A SUSTAINABILITY IMPACT-ASSESSMENT TOOL FOR SELECTED BUILDING TECHNOLOGIES IN RURAL INDIA: THE CASE OF THE ANDHRA PRADESH PRIMARY EDUCATION PROJECT

VOLUME – I OF II

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VOLUME – I

"*Declaration:* I hereby certify that the attached thesis is wholly my own work, and that all quotations from primary and secondary sources have been acknowledged."

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ABSTRACT

The United Nations Commission on Environment and Development, AGENDA 21, The Millennium Development Goals, etc. indicate that there is a worldwide concern for sustainable development. Construction is an essential human activity in development programmes. It is an important component of sustainable development. The decision makers should examine every construction project before it is implemented. Therefore, there is a need for an assessment tool to examine the sustainability impacts of construction. The existing assessment methods were found to be mostly based on environmental sustainability and thus, there was a need for developing an assessment tool, taking into account the social and economic issues also. The data and experience of the primary school construction project in a rural district of Andhra Pradesh (India) was adopted as a basis of assessment tool development

The aim of this dissertation was to provide an impact assessment tool for the decision makers to select sustainable building construction technologies in the context of social infrastructure development in rural India. It also aimed to demonstrate how to calculate the socio-economic and environmental impacts through the use of different walling and roofing construction technologies.

The dissertation's objectives were to examine the efficacy of the primary school construction project in Andhra Pradesh as a base for developing an impact assessment tool, to develop a process of calculation and determining the actual values of the socio economic and environmental impacts of selected building technologies, to demonstrate the selection process of the combination of walling and roofing technologies having optimum life cycle socio-economic and environmental impacts, to demonstrate the effect of weights on the selection process and to enable decision makers to develop databases on new construction and life cycle impacts in other contexts and to select sustainable building construction technologies.

An "Objective" type methodology was adopted in this dissertation. For example, the life cycle data was based on schools that were constructed and are ageing under uniform conditions of geo-climate, pattern of use, etc. Apart from that the data was on the consumption of materials, manpower, equipment, etc. required for different building construction technologies, which were all directly measurable at site. Therefore, the process of data collection was like a controlled trial and hence, it was "Objective" type. The analysis of the objectives of this dissertation and the conclusions were all based on quantified outputs. The criteria for assessing sustainability of the building technologies were life cycle cost of construction, employment opportunities created (by using labour-intensive technologies based on local materials), embodied non-renewable, renewable and waste energy and emission of CO_2 in a particular context.

The dissertation revealed that the walling and roofing systems based on local materials or with low cement and steel consumption had scored highly in Ranga Reddy, Andhra Pradesh. Therefore, solid brick wall, rat-trap bonded wall, cement stabilised mud block wall, stone roofing and brick corbel arch were suitable in the context of Ranga Reddy. Apart from being suitable options in Ranga Reddy, micro concrete tile roof and interlocking cement stabilised mud block wall would be suitable in other contexts where the climate is moderate, since their thermal insulations are low. One of the main reasons of high scores obtained by the brick intensive systems was the use of rice husk based brick production. This dissertation revealed that the weights beyond 128 did not have any significant effect on the scores obtained by different technologies.

The most important contribution of this dissertation was the process of developing the life cycle data. It demonstrated the process of selecting sustainable building technologies starting from creating database to the selection of appropriate walling and roofing technologies. By following this process a decision maker will be able to develop databases on new construction and life cycle impacts in other contexts, show the real scale impacts, rank the different options of walls and roof and finally select sustainable technologies. The quantitative assessment of different construction technologies demonstrated in this dissertation will put an end to ad-hoc decision making. This dissertation made substantial contribution in Indian and also in the wider context of sustainable development and construction and has addressed the construction related aspects of sustainable development as suggested by the the Department For International Development, AGENDA 21 and the Millennium Development Goals.

The impact assessment tool developed in this dissertation has addressed social, economic and environmental issues - all three pillars of sustainable development. This assessment tool has been adopted in sustainable school construction in South Africa, which indicates that it is replicable.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND OF THE DISSERTATION

In 1987 the United Nations Commission on Environment and Development drew attention to the fact that economic development often leads to deterioration, not an improvement, in the quality of people's lives (Brundtland, 1987). The Commission therefore called for a "Form of Sustainable Development", which meets the needs of the present without compromising the ability of future generations to meet their own needs

In 1992 the United Nations held a conference on Environment and Development (The Earth Summit) in Rio de Janeiro. In that conference the nations of the world agreed on an action plan for the next century, which recognised that humans depend on the Earth to sustain life and there are linkages between human activity and environmental issues. The action plan was termed as AGENDA 21, which is a comprehensive plan of action to be taken globally, nationally and locally by organizations of the United Nations System and in every domain in which human activities have impacts on the environment.

The Millennium Development Goals (2003) emphasized that the principles of sustainable development should be integrated into country policies and programmes and reverse the loss of environmental resources. The environment provides goods and services that sustain human development; so we must ensure that development sustains the environment. According to the "Report of the United Nations Conference on Environment and Development" (1992 updated:1999) the Environmental Impact Assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment.

Therefore, it appears that there is a worldwide concern for sustainable development. In this dissertation, the definition of sustainable development by Plessis (1999) was adopted (discussed in Chapter 2). According to him, there is little consensus about a definition for sustainable development. However, there are certain commonly accepted principles that can be used to guide sustainable development. He grouped them under the three parameters of environmental, economic and social sustainability.

Construction is an essential human activity in development. It is an important component of sustainable development since one tenth of the global economy is devoted to construction and operation of residential and office buildings (Der-Petrossian, 1999). According to Lippiatt (1999) buildings account for 40% of the energy and 16% of the water used annually worldwide. Der-Petrossian (1999) states that one sixth to one half of the world's major resources (energy being the most crucial one) are consumed by construction and construction related industries. The construction industry and the built environment are the main consumers of energy and material resources (Sjostrom and Bakens, (1999).

According to Lacasse (1999), the construction industry must examine certain consequences in the process of achieving sustainable development since it consumes a considerable amount of natural and physical resources and thus has a significant impact on the environment. The decision makers should examine every construction project before they are implemented as suggested by Davies (1999) and in chapter 4. Therefore, there is a need for an assessment tool to assess the impacts of construction.

It is important to note that in India, the scale of supply of social infrastructure is huge (discussed in chapter 3), and therefore, the Government should encourage the use of sustainable construction technologies across the country in the field of social infrastructure development. In India the term "social infrastructure" is used for primary school, primary healthcare and housing facilities (DFID letter ref: DPEP/Social Infrastructure, dated 30th April, 1999).

At present a large number of primary schools are being constructed (e.g., Sarva Shiksha Abhiyan- education for all) in 18 states of India. These projects are being implemented without any assessment as suggested by Agenda 21 (the author is an advisor to Sarva Shiksha Abhiyan). In a similar manner, primary healthcare and housing are the other areas where the sheer scale of construction is staggering as shown in chapter 3 and are being implemented without any assessment. The impacts of different options of materials and methods of construction on socio-economy and environment are different (discussed in Chapter 4). At present there is no system by which the national and district level decision makers or people in similar positions can assess the impacts of different construction technologies on socio-economy and environment.

It may be reiterated that the detailed discussions carried out in chapter 2 showed that the existing assessment methods are mostly based on environmental sustainability. In this context Todd and Geissler (1999) suggested that a regionally adaptable system that assesses the "green-ness" of buildings while taking into account the social and economic issues begins to address the sustainability of buildings. Hence, the aim of this dissertation is to develop an impact assessment tool for the decision makers to enable them to make decisions on sustainable social infrastructure by studying the socio-economic and environmental impacts of different options of construction technologies. However, in order to develop an assessment tool one should have the experience and data relating to social infrastructure construction project.

The Department for International Development (DFID) funded a primary school construction project in Andhra Pradesh, a Southern Indian state in 1995-96. The school buildings were constructed using different combinations of construction technologies at twenty nine sites of a rural district (Ranga Reddy) in Andhra Pradesh. According to the Census of India (2001), urban areas are those places that fall under administrative limits of municipal corporation, municipalities, etc., or have a population of at least 5,000 and have at least 75% male working population engaged in non-agricultural income pursuits and have a population density of at least 400 per square kilometre. Rural India comprises of all places that are not urban.

The author of this dissertation, with the help of specialist organisations, implemented the demonstration school building project between 1995 and 1996. At the end of 1998, DFID appointed specialist organisations to evaluate the performance of the cost effective schools (built in 1996). The author of this dissertation carried out further investigation as well as the actual repair works based on the evaluation team's suggestions in 2000.

This process of new construction and repair and upgrading of the primary schools in Ranga Reddy district of Andhra Pradesh were documented by the author. Therefore, the experience of the project and the data collected were examined to assess if it had the efficacy to be the basis of the impact assessment tool, the aim of this dissertation. The tool for impact assessment will help a decision maker to select appropriate construction technologies in a particular context of sustainable social infrastructure construction programme.

AIMS AND OBJECTIVES OF THE DISSERTATION

Aims

1. To provide an impact assessment tool for the decision makers to select sustainable building construction technologies in the context of social infrastructure development in rural India.

2. To demonstrate how to calculate the socio-economic and environmental impacts in a rural context through the use of different walling and roofing construction technologies.

OBJECTIVES

1. To describe the Andhra Pradesh Primary Education Project and examine its efficacy as a base for developing an impact assessment tool.

2. To develop a process of calculation and determining the actual values of the socio economic and environmental impacts of different cost effective construction technologies in the context of Ranga Reddy district.

3. To demonstrate the selection process of the combination of walling and roofing technologies for those which have optimum life cycle cost of construction, high employment opportunities (by using labour-intensive technologies based on local materials), low embodied non-renewable and renewable energy, high embodied waste energy and low emission of CO_2 in a particular context.

4. To demonstrate the effect of varying weights assigned to the socio-economic and environmental parameters for the scoring of technologies.

5. To enable decision makers to develop databases on new construction and life cycle impacts in other contexts and to select sustainable technologies.

SCOPE

It is important to note that this dissertation was not an attempt to provide an optimised solution on construction technologies in a particular location. It was intended to enable us to make informed choice. It may be noted that, while the quantitative analysis suggested in this dissertation is important, it will be meaningful only if one has understood the context. Therefore, this dissertation had a narrative part which explained the critical aspects of social infrastructure development in Andhra Pradesh so that decision makers could relate the quantitative analysis in other contexts.

The impacts of new construction and life cycle of complete buildings at 16 sites in Ranga Reddy district have been analysed in chapter 5 and 6. Based on these two chapters an impact assessment tool has been developed, which has considered the walling and roofing systems only. It may be noted that different roofing systems require different wall heights. For example, while the required wall height for a pyramid roof is 2.1 metres, it is 3 metres for all flat roofs. Hence, this dissertation has demonstrated the effect of combined roof and wall, which has been illustrated in chapter 5. This chapter has shown that the average cost of construction, labour cost and embodied energy of wall and roof combined (without finishes and waterproofing) are 58%, 59% and 73% respectively of that of a finished building. Therefore, walls and roofs together constitute a significant part of the complete structure. It may be noted that the data on walls and roofs in the assessment tool were complete in every respect, i.e., including the internal and external finishes (shown in chapter 8). This increased the share of unit cost, labour cost and embodied energy, e.g., unit cost becomes 64.3% of the total cost. Therefore, the dissertation has addressed the impact of the significant part of a finished building.

Let us now examine the issue of eliminating foundation, doors, windows and floor finishes from the scope of this dissertation. It may be noted that in Ranga Reddy district, wall footing with coursed rubble stone was the only feasible option for a single storey school building. Similarly all the door and windows were made of local timber and all the floors had a stone finish. As a contrast, there was a wide variation of walling and roofing technologies. Since this dissertation intended to calculate the scores of the different options of technologies on a comparative basis, only wall and roof have been considered for impact assessment. However, in situations where a number of options are available for foundation, door, window and floor finish, the impact of a finished building should be considered.

1.2 METHODOLOGICAL ISSUES

The data and experience of school construction discussed above should be examined from the methodological point of view first and then it must be combined to evolve an impact assessment tool. Dooley (1997) states that while science pursues the empirical methods, which are based on experience of the world, philosophers disagree about how far we can trust our observations. While referring to the debate in this regard Dooley refers to Guba (1990), Hughes (1990), Little (1991) and Roth (1987). Dooley (1997) states that, in social sciences empiricism sometimes goes by the name positivism, which rejects speculations. In this regard social sciences share a unity of methods with the natural sciences. That is, we can test theories by seeing how well they fit the facts that we observe. According to Dooley although no consensus has formed around an alternative view, traditional positivism has many critics.

In the context of methods of analysis in housing issues, Tipple and Willis (1991) state that, following the physical sciences, social sciences try hard to develop a theoretical and methodological perspective to be as "objective" as possible in its analysis and in the approach of the investigator; and to quantify the outputs of projects and policies as much as possible. The range from intuitive to the highly quantifiable represents both a continuum and a dichotomy. It is often the subject of fierce debate between seemingly opposing factions.

According to Tipple and Willis (1991), the issue of subjectivity and objectivity in analysis can be thought of in terms of the methods or procedures by which a conclusion has been reached. An inquiry is "objective" when the conclusions are based on some formal model which can be quantified, or worked through. An objective investigator is one who has not adopted a particular technique simply because it will produce the desired conclusions; nor manipulated data; nor excluded part of the data because it does not conform to his/her belief.

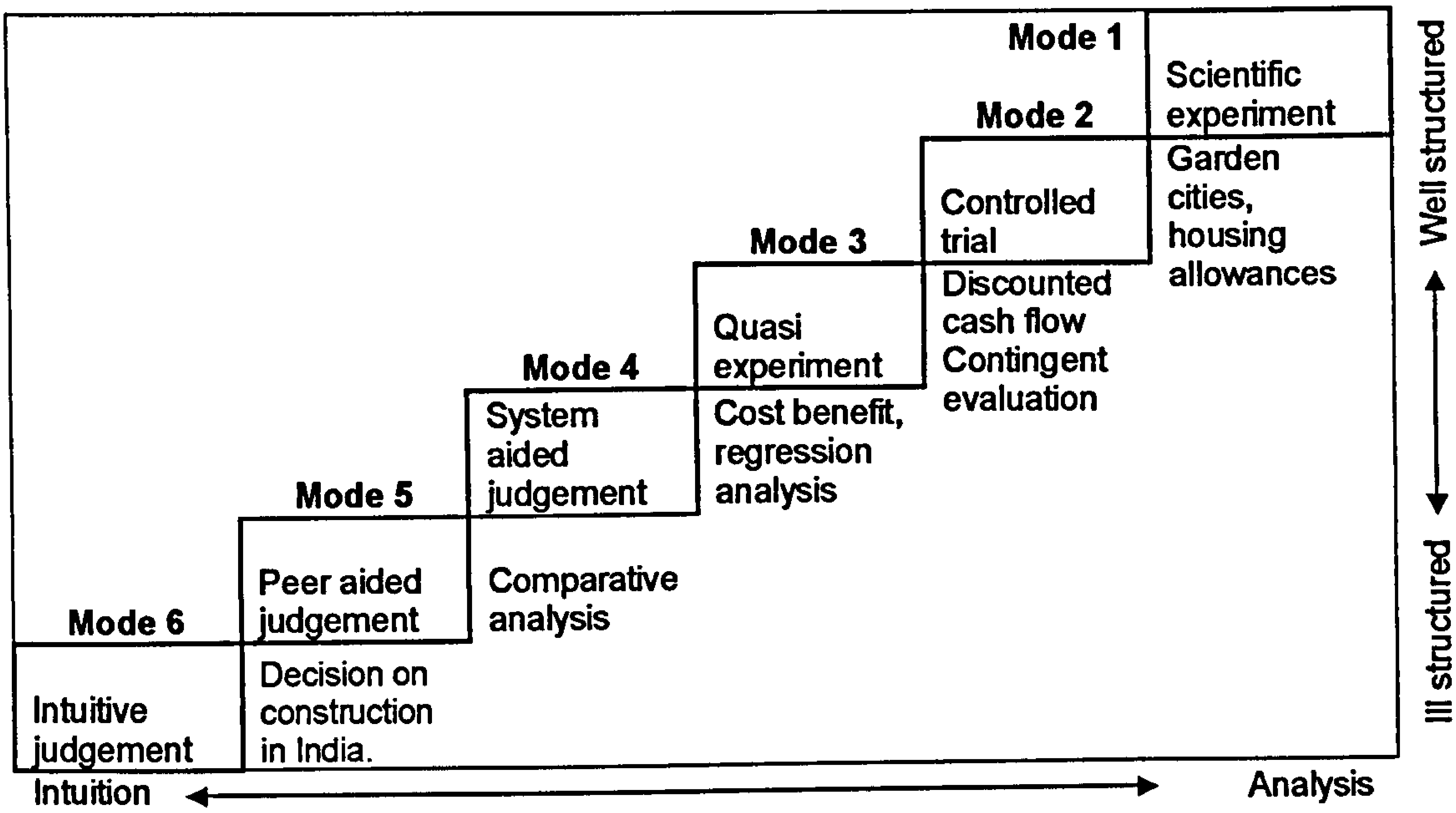
Table 1.1 Objectivity and subjectivity in enquiry and analysis.

Method of analysis is	Investigator is	
	Subjective (i.e. prejudiced)	**Objective (i.e. not prejudiced)**
Subjective (i.e. personal judgement is used)	1	2
Objective (i.e. no personal judgement is used)	3	4

Source : Tipple and Willis (1991: 4)

Table 1.1 shows the four possibilities. A subjective analysis is the one in which personal judgement has been used or the analyst is prejudiced (cell 1). According to Tipple and Willis (1991:4) *"the more 'objective' the analyst/inquirer, and the more 'objective' the method of analysis, the better are the results, predictions, and policy recommendations likely to be"*. According to them, it is considered desirable to have investigations of the 'cell 4' type in the above table. Tipple and Willis (1991) state that viewing evaluation or analysis as a simple dichotomy between 'subjectivity' and 'objectivity' is perhaps too simplistic a way of looking at evaluation methods and techniques. They refer to a more sophisticated framework to consider the whole equation of analytical method, provided by Hammond's (1978) 'cognitive continuum', based on the notion that most cognitive analysis involves both intuition and analysis in varying degrees.

Figure 1-1 Hammond's cognitive continuum showing different modes of analysis



Source : Based on Tipple and Willis (1991: 6)

The most intuitive mode, mode 6, occurs whenever an individual is operating with minimum support from colleagues or reference to impersonal aids. While taking decisions on which construction technology to recommend for school construction in District Primary Education Project (India), the executive engineer in the district administration decides this based on her/his own experience, which is an example of intuitive judgement. The most well structured approach is the mode 1, i.e., scientific experiments. Let us now examine this dissertation with respect to Tipple and Willis (1991) and Hammond's (1978) cognitive continuum (shown in Figure 1-1).

1.3 METHODOLOGY ADOPTED IN THIS DISSERTATION

Tipple and Willis (1991) state that the scope for quasi-experiments, and especially controlled trials and scientific experiments are much more limited in social science than in the physical (physics and chemistry) and biological sciences. It is more difficult in the social sciences to alter one variable to observe its impacts. However, it may be noted that the DFID funded pilot project on cost effective school construction in Andhra Pradesh may be put under the category of controlled trials. The author of this dissertation was the overall supervisor of the project. Such examples are very rare. As discussed in chapter 5 and 6, school buildings were constructed at 29 sites (within 40 kilometres diameter) under the Andhra Pradesh Primary Education Project. It was a pilot project designed to test the cost effectiveness, income generating capacity and the extent of environmental damage owing to the use of different options of construction technologies. These buildings were constructed at the same point of time, under the same degree of supervision; they have the same end use (i.e., primary school) and are being used by one ethnic group. They are ageing under uniform conditions like in a laboratory. Therefore, it is like a controlled trial shown in Figure 1-1 and hence, the project created room for "objective" type data collection (i.e., cell 4).

Based on Tipple and Willis (1991), "Objective-type" methodology has been adopted in this dissertation. Figure 1-2 shows the entire process of the dissertation. Quantitative analysis has been adopted to achieve the five objectives of this dissertation (Box-2, Figure 1-2). For example, to achieve the objective-1, the experience of Andhra Pradesh school construction project has been examined (Box3, Figure 1-2) in terms of quantities of impacts which revealed that the project experience had the efficacy to act as the basis of development of an impact assessment tool (chapter 5 and 6). The impact assessment tool (Box-4 in Figure 1-2) had inputs from Box-5 (Figure 1-2) that were "Objective" type and the outputs were in terms of quantities. Based on that, the conclusions regarding sustainable construction technologies have been drawn. The demonstration of real scale impacts of new and life cycle construction along with scoring of these technologies in a context were all based on quantitative analysis.

At this point it is important to discuss the detail of the methods adopted in "Data Collection and Analysis", "Method of Evaluation" and "Weightings", the core of this dissertation. The methods adopted in these have been explained in the following three sections –

1. The data collection process based on Andhra Pradesh School Construction project. The method of data analysis has been based on the Microsoft Excel worksheets to examine the efficacy of the project as the basis of impact assessment tool (explained in section 1.3.1).

2. Based on the above, the actual quantities of the impacts of different construction technologies have been calculated in chapter 8 and 9. The assessment tool has been developed in Microsoft Excel worksheets that calculate the new and life cycle impacts of selected building technologies in a particular context. The technologies' scores also have been calculated on an index scale. (explained in section 1.3.2).

3. In absence of any acceptable method of weighting, this dissertation has demonstrated the effect of weighting instead of suggesting a definite set of weights. A discussion on weighting has been carried out in section 1.3.3.

Figure 1-2 Diagram showing the whole process of the dissertation

Box-1

With Andhra Pradesh as a background, exploring the possibilities of addressing the problem of supplying the huge shortfall of social infrastructure under the Basic Minimum Services in India.

- Construction technologies may be an opportunity for employment generation and a threat to the environment as well.
- At present tool to assess the impacts of construction technologies on the socio-economic and environmental aspects of social infrastructure construction does not exist.

Box-2

<u>AIMS</u>

1. Providing an impact assessment tool for the decision makers to select sustainable building construction technologies in the context of social infrastructure development in rural India.

2. Demonstrating how to calculate the socio-economic and environmental impacts through the use of different walling and roofing construction technologies.

<u>OBJECTIVES</u>

1. To describe the Andhra Pradesh Primary Education Project and examine its efficacy as a base for developing an impact assessment tool.

2. To develop a process of calculation and determining the actual values of the socio economic and environmental impacts of different cost effective construction technologies in the context of Ranga Reddy district.

3. To demonstrate the selection process of the combination of walling and roofing technologies for those which have optimum life cycle cost, high employment opportunities, low embodied non-renewable and renewable energy, high embodied waste energy and low emission of CO_2 in a particular context.

4. To demonstrate the effect of varying weights on scoring.

5. Enabling decision makers to develop databases on new construction and life cycle impacts in other contexts and to select sustainable technologies.

Box-3

The new construction and repair experience of the Andhra Pradesh experience is described and examined in chapter 5 and chapter 6.

The examination revealed that the project experience could be used as a basis of impact assessment tool. There are several feasible construction technologies and their impacts on socio-economy and environment vary significantly. The data of this project is an asset.

Box-4

Based on the Andhra Pradesh experience and the literature survey (chapter 2), chapter-7 identifies socio-economic and environmental parameters as criteria for impact assessment of different construction technologies on social infrastructure development.

Based on a review of the methods of evaluating the socio-economic and environmental impacts in chapter-2, the index method of scoring has been adopted in chapter 7. This chapter discusses the issue of weighting and states that the effect of varying weights on scoring will be demonstrated in this dissertation.

Box-5

Chapter 8 and 9 develop a process of data collection and also calculate the actual values of the nine socio-economic and environmental impacts of 6 walling and 11 roofing systems (new and life cycle).

Box-6

Chapter- 10 demonstrates the impact assessment of new construction

Chapter-11 demonstrates the life cycle Impact assessment

Chapter-12 carries out a study on the effect of varying weights on scoring for life cycle and new construction.
Decision making based on scoring

Assumptions

Rupees 100 million (£1.25 million) investment in a district

5.5m x 5.5m one classroom unit

Impacts of 66 combinations of wall and roof for new construction and Life cycle of 1,068 classrooms

Data on wall and roof as finished products.

Box-7

Provides detailed information on the socio-economic and environmental impacts of the 66 combinations of walling and roofing systems so that the decision maker can choose the most appropriate combination of wall and roof in a context.

Box-8

Conclusions- reviewing the aims, objectives, assumptions and limitations, key findings and conclusions, contribution of the dissertation, recommendations, scope for future research, post script etc.

1.3.1 DATA COLLECTION AND ANALYSIS

As observed by Tipple and Willis (1991), one of the important issues in any method of analysis is the quality of data. Ashworth (1993) observes that there is a lack of data for life cycle cost forecasting. It may be noted that the DFID funded Andhra Pradesh Primary Education Project offered a good opportunity for data collection on new construction and maintenance requirements of eleven roofing and six walling systems (including the conventional options).

The issue of quality of such data can now be examined, which depends upon the way data collection system has been designed and also the people involved in the process. One can reduce the subjectivity of the data collectors by developing a suitable system. In the Andhra Pradesh Primary Education Project, the main focus was to generate analysis of rates per unit plan or elevation areas of the alternative items such as the rat trap bonded wall and precast ferrocement channel roofing. The analysis of rates provided the consumption of materials, labour, equipment, etc., which was used to calculate the environmental impacts. Alternative here means those technologies which are other than the conventional cement and steel intensive construction systems. The existing Government schedule had the latter option only.

The process of data collection in Andhra Pradesh Primary Education Project was intended to generate "objective" data which refers to "cell 4" as shown in Table 1.1. Since the data was on the consumption of materials, manpower, equipment required for the alternative construction systems, they were all directly measurable at site. For example, if "x" cubic meter of masonry work in rat trap bonded brick wall has been done in one day, the amount of cement, sand, brick, scaffolding, water, etc., consumed could be recorded. Thus the process of data collection hardly left any room for subjectivity of the inquirer. However, there were a few conflicting forces in the process of data collection that needed attention. In the school construction project, the contractor had a tendency to increase his bills. The site supervisors' sincerity had to be monitored. The specialist agencies' representatives had a tendency to show low figures to prove that the technology promoted by them was low cost. The author had envisaged such situation in advance because of his prior experience elsewhere and had to collect data on his own by directly measuring and recording at site. It was an uphill task to come to agreements with each other as there were frequent arguments among the inquirers involved in the process of data collection. The database generated under the Andhra Pradesh Primary Education Project was the result of this process, which was in the end approved by the State Government. Although there were many people involved in data collection, the author of the dissertation, the then consultant to DFID, had developed and designed the forms and process of data collection shown in Figure 1-3 and Figure 1-4.

Figure 1-3: The process adopted for new construction in the Andhra Pradesh Primary Education Project (DFID Funded). This is to be read in conjunction with Figure 1-4.

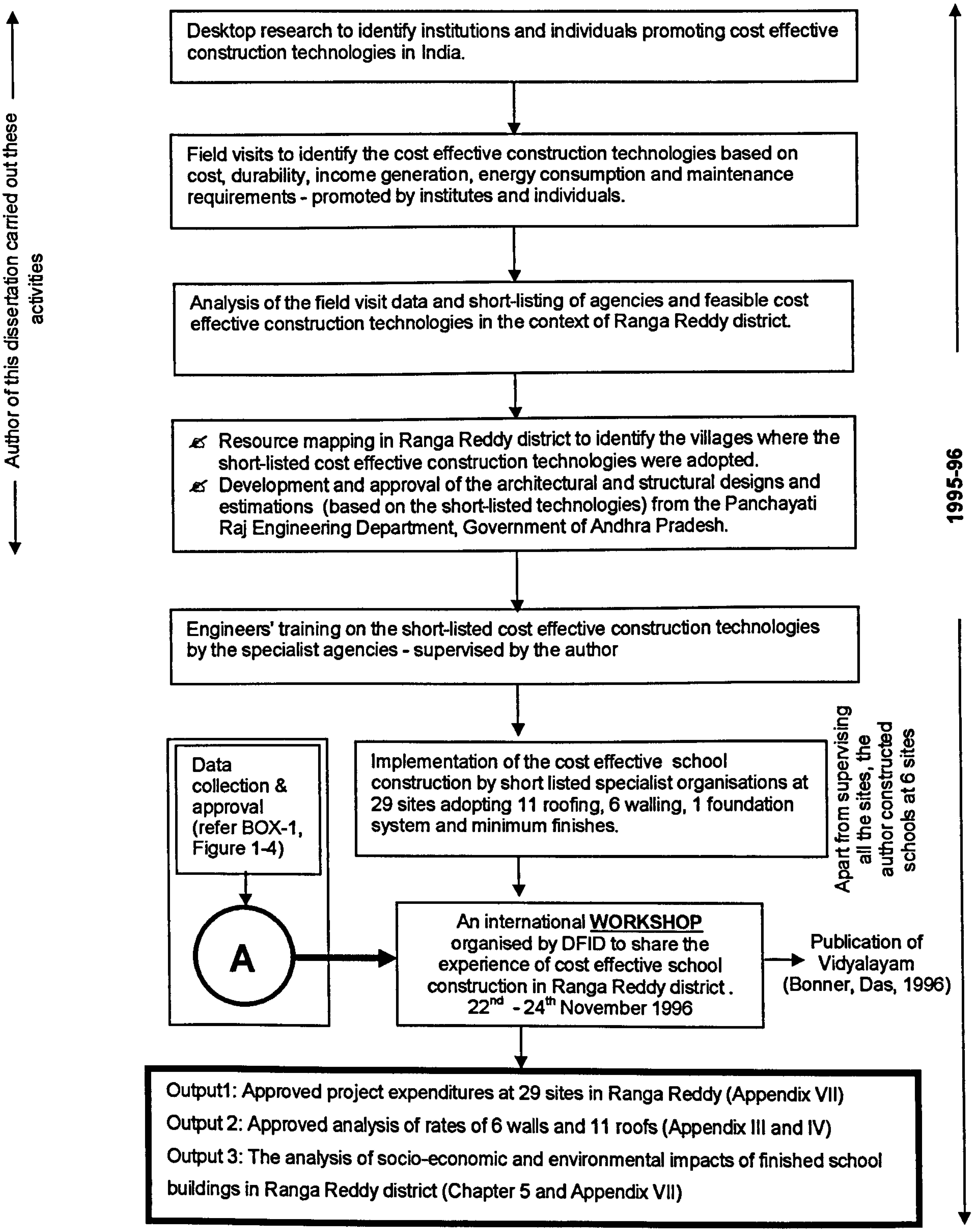


Figure 1-4 The detail of site level data collection and the process of obtaining approval.

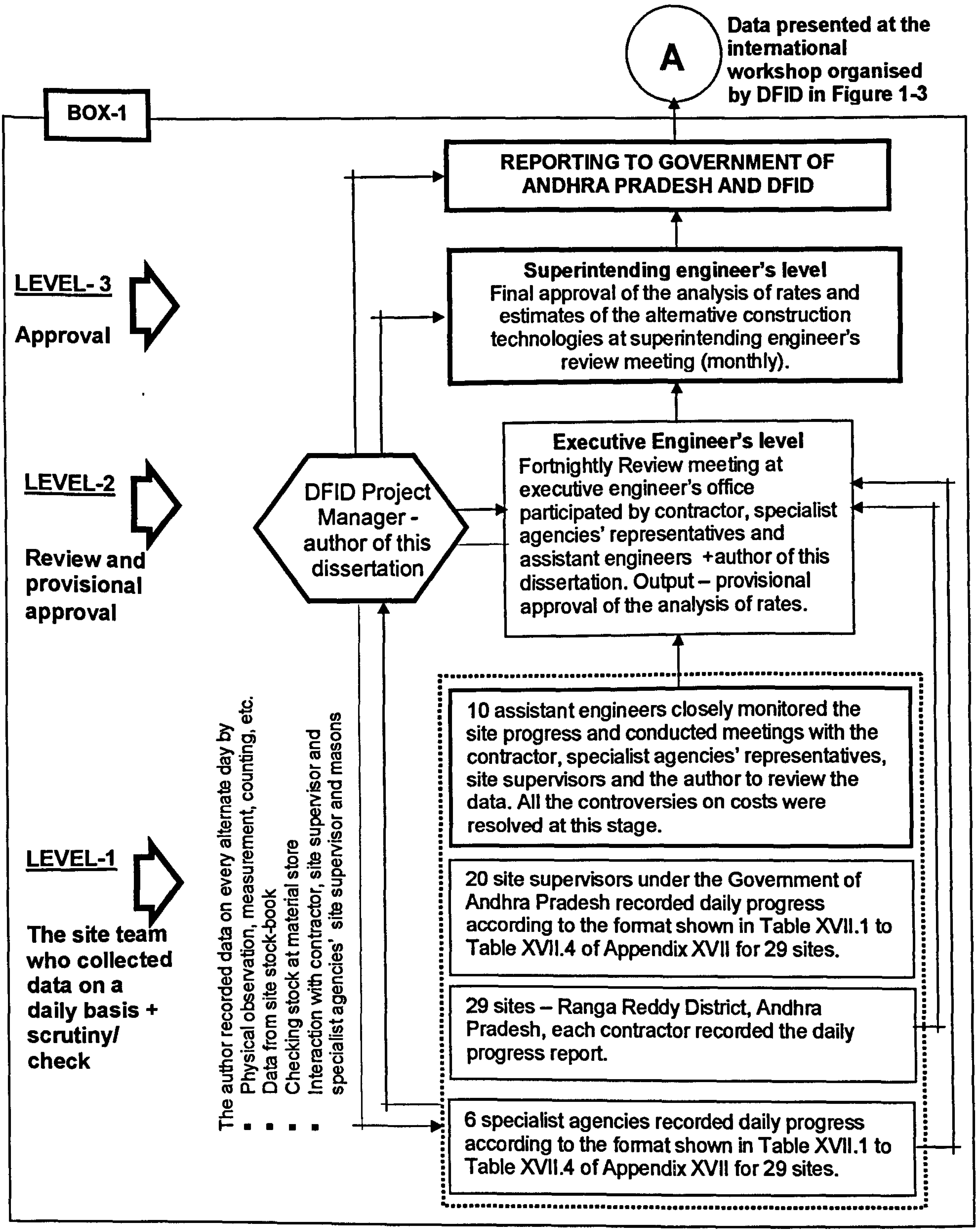


Figure 1-3 shows the overall process of Andhra Pradesh Primary Education Project. Figure 1-4 shows the process of obtaining site specific data from the 29 villages in Ranga Reddy district. The data collected in this process may be accepted to be close to "cell 4" type. One of the important outputs of Andhra Pradesh Primary Education Project was the analysis of 11 roofs and 6 walls including the conventional technologies, i.e., how much and what types of materials, skilled, semi-skilled, unskilled workers, equipment such as vibrators, mixers, scaffolding, etc. were required per unit area of walls and roofs. The data collected in this process has been used in chapter 5, 8 and 9 for socio-economic and environmental impact analysis.

It has been mentioned earlier that the school buildings in Andhra Pradesh are ageing under uniform conditions as in a controlled trial. Figure 1-5 shows how the data collection regarding the ageing of the buildings was conducted, which generated the database for life cycle impacts of the walling and roofing systems. As explained in chapter 6, the buildings did not show any structural safety problems during the interventions carried out in 2000. The most commonly occurring defect was the waterproofing treatment, which was termed as corrective. The preventive maintenance interventions such as cleaning, painting, etc., were also observed. This process helped in generating the analysis of rates for corrective and preventive interventions required for 11 roofing and 6 walling systems. The foundations did not have any defect. Based on the process of data collection shown in Figure 1-5, analysis of rates, i.e., the amount and types of materials, equipment and manpower required were obtained (Appendix XVI and VI). Chapter 6 has discussed the issue of the frequency of interventions. Therefore, the new construction and Repair and Upgrading Programme in Andhra Pradesh have provided data on life cycle implications of 6 walling and 11 roofing technologies. Life cycle data on conventional systems were available with the Government engineers in Andhra Pradesh. The following pages show the process of data collection on life cycle impacts of the school buildings under the Repair and Upgrading programme.

Figure 1-5: The life cycle data collection process of 11 roofs and 6 walls under the Andhra Pradesh Primary Education Project. This is to be read in conjunction with Figure 1-6.

Repair and Upgrading Programme of the schools at Ranga Reddy by DFID in 1998. ITDG (UK) + National Council for Cement and Building Materials (India) were appointed to carry out investigation on the effect of ageing on the schools constructed in 1995-96.

Field investigation, analysis and recommendation by the evaluation team.

An international **WORKSHOP** in November, 1998 was organised by DFID for sharing the results with the participants engaged in social infrastructure building, policy makers, bureaucrats, etc.

Appointment of the author as a consultant by DFID to implement the repairs recommended by the evaluation team.

The author conducted all these

- Capacity building of Government engineers and community on repair.
- Condition assessment of the schools with the help of Government engineers and community (for implementation work process and site record keeping). Defect analysis and recommendations
- Preparation of estimates for repair and provisional approval
- Implementation at 29 sites
- Data collection (refer BOX-2, Figure 1-6)

This process is in the Appendix –VIII and Appendix- IX

1998-2000

Submitted to the Government of Andhra Pradesh for approval (refer Figure 1-6)

B → Approval of the site specific quantities and the rates of repair by the Government of Andhra Pradesh.

Report submitted by the author to the DFID New Delhi.

Output1: Approved analysis of the preventive and corrective repair items for 11 roofing and 6 walling systems along with the frequencies of interventions.

Output2: The life cycle impacts of the schools at 29 sites.

Figure 1-6 The process of field level data collection under the Repair and Upgrading Programme, Andhra Pradesh Primary Education Project.

Submitted to the Government of Andhra Pradesh for approval - Input to Figure 1-5

B

BOX-2

Data Collection Process.

- The author, the assistant engineers and the work assistants were part of the School Committees. They used to be present in the meetings and assist the School Education Committees in case of confusion.
- The School Committees kept the accounts and settled the bills in meetings, which were checked by the author and the Government engineers. A few general body meetings were conducted to inform the villagers about the progress of the programme. Author of this dissertation was present in all the meetings.

Cashbook : Receipt of money in the school committee bank account- Refer Table XVII.5 A of Appendix XVII.

Cashbook : Expenditure- Refer Table XVII.5 B of Appendix XVII.

Daily progress report – date, description of the job, number of masons, helpers, volume of work done, money paid, etc.- Refer Table XVII.5 C of Appendix XVII.

Data Approval Process.

The District Collector's office forwarded it to the Government of Andhra Pradesh.

Executive engineer approved the rates and forwarded them to the District Collector, Ranga Reddy.

Deputy executive engineers checked and forwarded the bills to the executive engineer.

Assistant engineers with the help of the author checked and forwarded the bills to the deputy executive engineer.

On completion of the Repair and Upgrading, general body meetings of the School Committees took place at 29 sites.
Bills, vouchers and statement of expenditure according to the site book format in Table XVII.5 A, B and C of Appendix XVII were approved by the respective School Committees in June 2000.

The author of this dissertation and the respective assistant engineers, Government of Andhra Pradesh were present in all such meetings.

Figure 1-5 and Figure 1-6 show the process of life cycle data collection for the construction technologies adopted in Andhra Pradesh Primary Education Project. The data on new construction and life cycle impacts have been based on a village named Jaggamguda. This data has been analysed in three Microsoft Excel files, which are hyperlinked. The process of calculations in File-2 (new construction) and File-3 (repair) has been shown in Figure 1-7. The hyperlinked worksheets "A", "B", "C", "D" and "G" shown in Figure 1-7 are in File-1 (Figure 1-8).

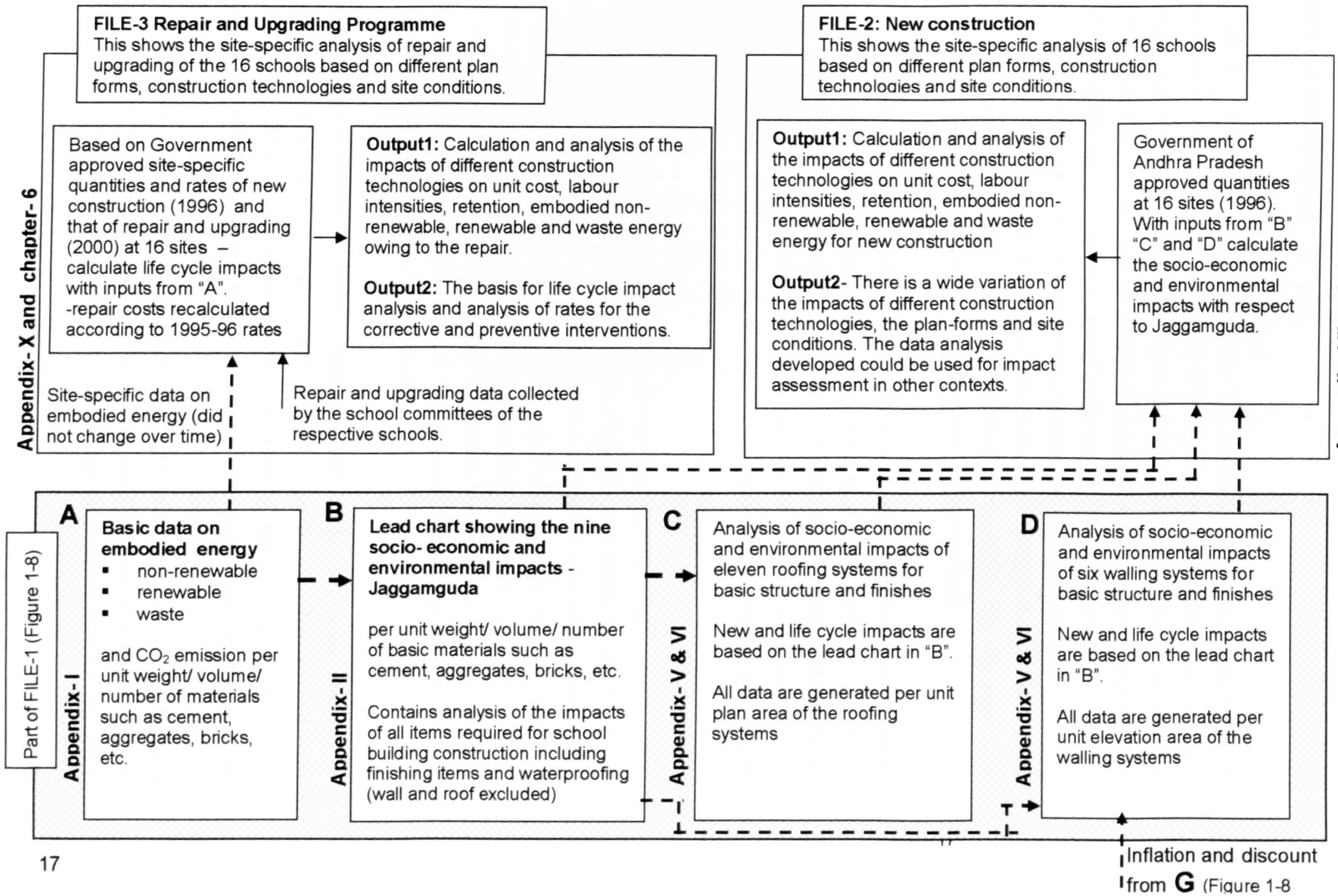
The worksheet "A" in File-1 (Figure 1-8), based on the data collected on life cycle and new construction, carries out calculations on embodied energy and CO_2 emission of basic materials such as cement, aggregate, brick, etc. The worksheet "B" in File-1 calculates the nine socio-economic and environmental impacts of the same basic materials. This worksheet also calculates the conventional construction items such as excavation, floor finishing, white washing, etc., based on the Government approved analysis of rates. The worksheet "C" and "D" (both in File-1) calculate the nine socio-economic and environmental impacts of the cost effective roofing and walling systems. The File-2 (in Figure 1-7), with inputs from worksheets "B", "C" and "D", calculates the socio-economic and environmental impacts of 16 sites in Ranga Reddy district. Out of 29 sites, 16 have been considered in File-2 since the remaining were repetition of the conventional steel and cement intensive systems. The analysis of Andhra Pradesh school construction experience in Chapter 5 is based on this calculation.

Chapter 5 has shown that the Andhra Pradesh experiment has provided a deep insight into the impacts of different construction technologies adopted in primary school construction on the socio-economy and environment. This chapter also demonstrated that the architectural design and site conditions regulated the socio-economic and environmental impacts significantly.

The File-3 in Figure 1-7 calculates site specific impacts of the Repair and Upgrading Programme of the Andhra Pradesh Primary Education Project carried out in 1999-2000. Based on the calculations in File-3, chapter 6 carried out a detailed site-specific analysis of the life cycle impacts on the socio-economy and environment in Ranga Reddy district.

The site-specific data of 2000 in chapter 6 has been transformed into 1995-96 rates. The site specific energy data has been adopted from worksheet "A" of File-1(Figure 1-7). The analysis of new and life cycle impacts of different construction technologies shown in chapter 5 and 6 is the backbone of this dissertation.

Figure 1-7 The process of calculating site-specific data on life cycle and new construction of school buildings built in Ranga Reddy district. Worksheets "A","B","C", "D" and "G" are from File-1 (Figure 1-8). Dotted lines indicate hyperlink.



1.3.2 METHOD OF ANALYSIS

It may be reiterated that the aim of this dissertation is to provide an impact assessment tool and also to demonstrate how to calculate the impacts of different walling and roofing systems. One of the important aspects of the assessment tool is the parameters involved in impact assessment. Following Plessis's (1999) suggestion (in chapter 2), society, economy and environment, the three pillars of sustainability, have been accepted as the basis of impact assessment. Chapter 7, based on chapter 2, 5 and 6; has identified nine socio-economic and environmental parameters that were used for assessing the impacts of construction technologies based on the data collected by the process described above. Having identified the parameters, the next step was to develop a method to assess the impacts of different construction technologies.

In this dissertation, impact assessment on socio-economy and environment has been carried out in three stages, viz., 1) demonstrating the quantitative impacts of new construction of different combinations of walling and roofing technologies adopted in the school buildings of Ranga Reddy district, Andhra Pradesh, 2) impact assessment of the same for the whole life cycle, 3) calculating the scores of the different combinations of walls and roofs for both new construction and life cycle of buildings.

The assessment tool is for the decision makers and hence, the impact per square metre of plan area will not give them a realistic idea since the scale of infrastructure supply in India is huge. As explained in chapter 10, the stage I of assessment has shown the nine socio economic and environmental impacts of 1,068 classrooms (new construction) owing to the use of 66 combinations of walls and roofs. Stage II of the assessment has shown the life cycle socio-economic and environmental impacts of 1,068 classrooms built by adopting the same 66 combinations. The Microsoft Excel sheets "E" and "F" (corresponding to stage I and II) shown in Figure 1-8 have been used in the impact assessment.

The stage III needed a method of scoring. There is a wide range of methods available for evaluation and ranking described in chapter 2 and chapter 7. It may be noted that, out of the nine socio-economic and environmental parameters, the units of the first five are in rupees, the sixth to eighth are in Mega Joules and the ninth in tons. This dissertation has adopted the index method of scoring (explained in chapter 7) to homogenise the different units of the parameters. Chapter 7 explained that a group of technological options adopted in the school buildings of Ranga Reddy district were to be evaluated against the nine socio-economic and environmental criteria. The different combinations of walling and roofing technologies have been assumed as the students in a class and the nine socio-economic and environmental criteria as the examination papers. The index method of analysis in chapter 12 explained the entire process. Final scores of the 66 combinations based on index method have been calculated in worksheet "G" (Figure 1-8).

The whole process of real scale impact assessment of new construction and life cycle has been shown in Figure 1-8. The File-1 is a Microsoft Excel worksheet. It contains worksheets "A", "B", "C", "D", "E", "F" and "G". As mentioned before, the worksheet "A" calculates the embodied energy and CO_2 emission owing to the procurement of raw materials, transportation of raw materials to the production yard, production and transportation of the finished product to the site. Similarly the worksheet "B", hyperlinked with "A", calculates the nine socio-economic and environmental impacts of all the conventional items (other than wall and roof) such as excavation, floor finish, plastering, white washing, etc. The worksheet "C" and "D", both hyperlinked with "B" and "G", calculate the nine socio-economic and environmental impacts of 11 roofing systems and 6 walling systems (new and life cycle). The rate of inflation and discount rates are obtained from "G".

The worksheets "C" and "D" on roofing and walling systems (Figure 1-8) are the two major inputs to the worksheets "E" and "F" where the new and life cycle impacts of 66 combinations of 1,068 classrooms have been calculated. Worksheet "G" acquires data from "E" and "F" and calculates the indexes of the 66 combinations for new construction and life cycle.

If one wants to use these worksheets in another context, one has to update the lead charts shown in screen dumps (Figure 1-9) of "A-Energy & CO_2", "B-Lead chart" and inflation and discount rate in "G-Socio-env LC score". In case of addition of a new technology or alteration of an existing wall or roof, only the analysis of rates in "C-Roof" and "D-Wall" have to be modified.

Figure 1-8: Microsoft Excel worksheets for calculation of impacts for new construction (E), life cycle (F) and scoring (G).

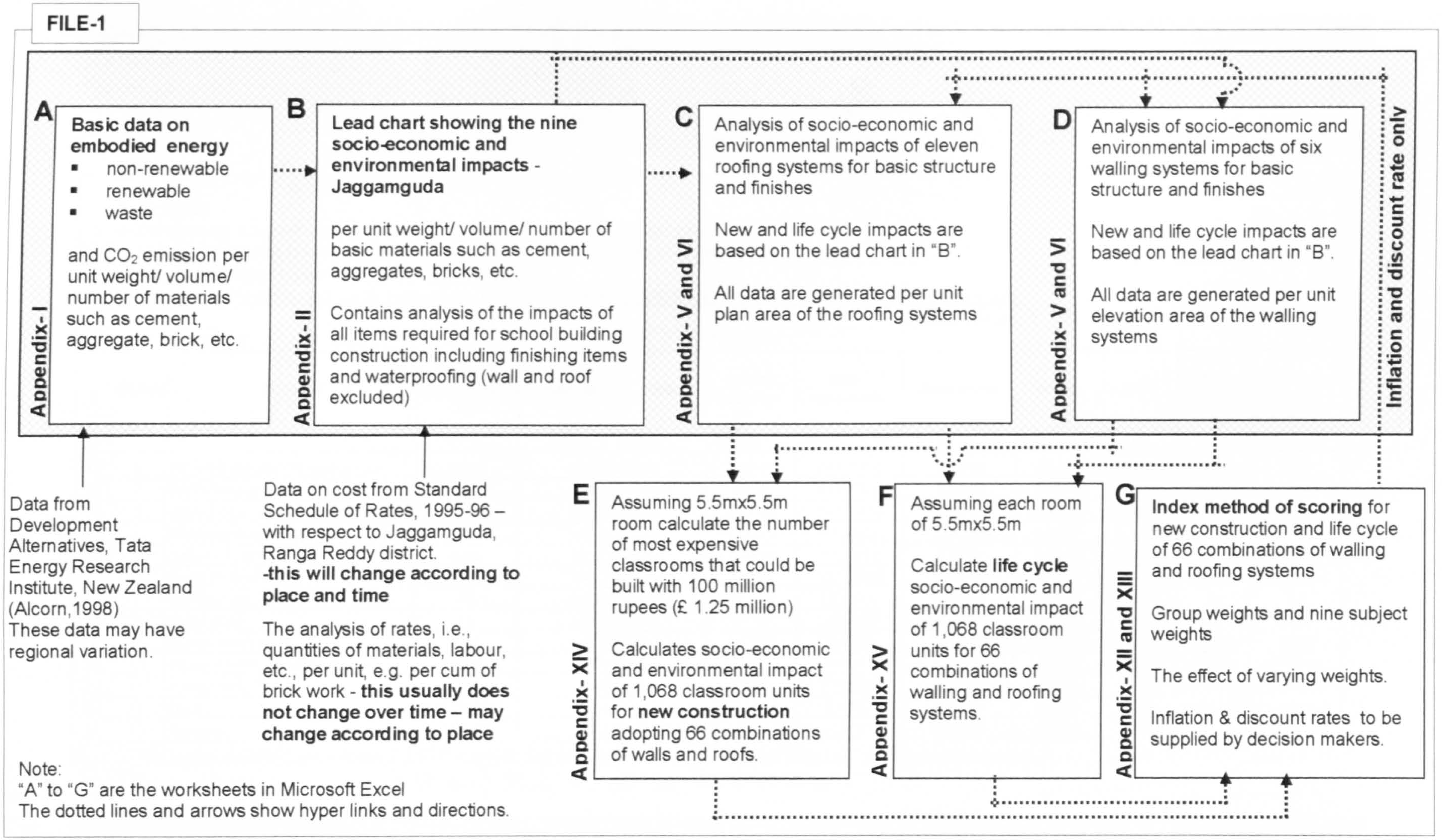
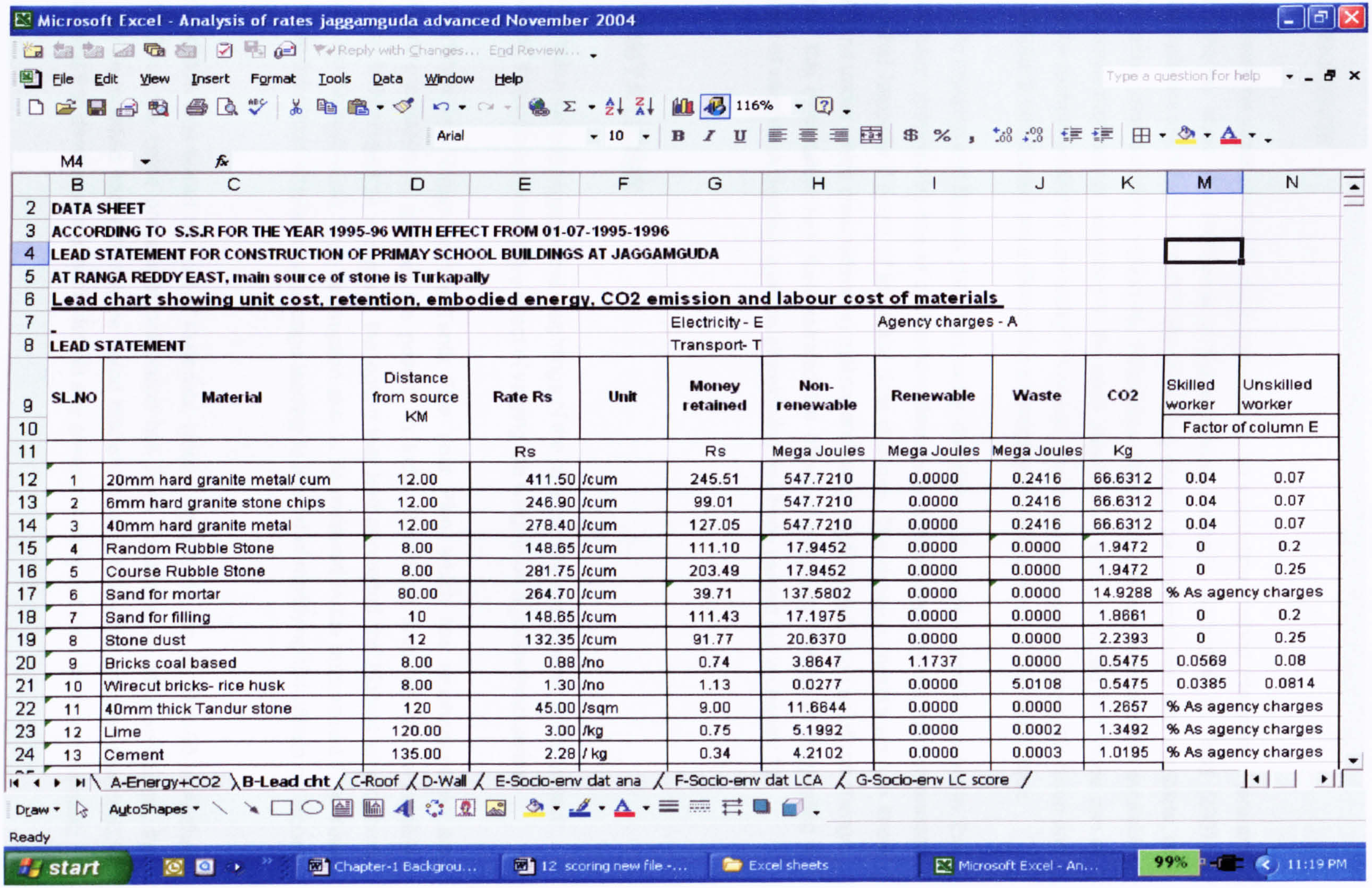


Figure 1-9 Screen dump of worksheet "B" of FILE-1 showing the lead chart for calculating socio-economic and environmental impacts of materials such as bricks, cement, etc



DATA SHEET

ACCORDING TO S.S.R FOR THE YEAR 1995-96 WITH EFFECT FROM 01-07-1995-1996

LEAD STATEMENT FOR CONSTRUCTION OF PRIMAY SCHOOL BUILDINGS AT JAGGAMGUDA

AT RANGA REDDY EAST, main source of stone is Turkapally

Lead chart showing unit cost, retention, embodied energy, CO2 emission and labour cost of materials

Electricity - E   Agency charges - A

Transport- T

LEAD STATEMENT

SL.NO	Material	Distance from source KM	Rate Rs	Unit	Money retained	Non-renewable	Renewable	Waste	CO2	Skilled worker	Unskilled worker
										Factor of column E	
			Rs		Rs	Mega Joules	Mega Joules	Mega Joules	Kg		
1	20mm hard granite metal/ cum	12.00	411.50	/cum	245.51	547.7210	0.0000	0.2416	66.6312	0.04	0.07
2	6mm hard granite stone chips	12.00	246.90	/cum	99.01	547.7210	0.0000	0.2416	66.6312	0.04	0.07
3	40mm hard granite metal	12.00	278.40	/cum	127.05	547.7210	0.0000	0.2416	66.6312	0.04	0.07
4	Random Rubble Stone	8.00	148.65	/cum	111.10	17.9452	0.0000	0.0000	1.9472	0	0.2
5	Course Rubble Stone	8.00	281.75	/cum	203.49	17.9452	0.0000	0.0000	1.9472	0	0.25
6	Sand for mortar	80.00	264.70	/cum	39.71	137.5802	0.0000	0.0000	14.9288	% As agency charges	
7	Sand for filling	10	148.65	/cum	111.43	17.1975	0.0000	0.0000	1.8661	0	0.2
8	Stone dust	12	132.35	/cum	91.77	20.6370	0.0000	0.0000	2.2393	0	0.25
9	Bricks coal based	8.00	0.88	/no	0.74	3.8647	1.1737	0.0000	0.5475	0.0569	0.08
10	Wirecut bricks- rice husk	8.00	1.30	/no	1.13	0.0277	0.0000	5.0108	0.5475	0.0385	0.0814
11	40mm thick Tandur stone	120	45.00	/sqm	9.00	11.6644	0.0000	0.0000	1.2657	% As agency charges	
12	Lime	120.00	3.00	/kg	0.75	5.1992	0.0000	0.0002	1.3492	% As agency charges	
13	Cement	135.00	2.28	/ kg	0.34	4.2102	0.0000	0.0003	1.0195	% As agency charges	

1.3.3 WEIGHTINGS

Weights should be associated with each parameter in an evaluation method. However, there are several critiques about the limitations of the weighting methods. According to Todd (2001), weighting systems are fraught with difficulty since they cannot be accomplished with complete, or in some cases, any, scientific objectivity. Finnveden (1999:34) critically reviewed the available and operational methods of weighting in life cycle assessment and concluded that *"none can at this stage be recommended for use today"*. However, one cannot completely avoid this issue and hence, chapter 2 has carried out a discussion on weighting in the context of this dissertation.

According to Nijkamp and Spronk (1981), in reality, decision-makers are seldom interested in 'the' optimal solution provided by one or another decision method. Normally they are more interested to know what happens if some of the initial data changes. The decision-makers want to know whether (and under which circumstances) optimal and pareto-optimal (efficient) solutions change. Therefore, this dissertation has demonstrated the effect of weighting instead of suggesting a definite set of weights. A detailed analysis of weighting has been carried out in chapter 12.

1.4 LIMITATIONS

This dissertation did not suggest final weightings of the nine parameters adopted in the impact assessment; it has demonstrated the effect of varying the weights on a geometrical series.

The dissertation was based on the Tenth Five Year Plan, which has emphasised on the employment generation in view of the poverty in India. Based on that, out of the feasible construction technologies in a context, the option that had generated the highest employment was given the highest score. This assumption should be reviewed in the subsequent Five Year Plans, when the circumstances may change leading to a need of modifying the criteria for labour intensity.

This dissertation was based on cost of materials, labour, equipment, etc. in 1995-96 in Andhra Pradesh. Since the entire process of calculation has been developed on Microsoft Excel, the values can be modified easily. It may be noted that one should follow the process described in chapter 8 and 9 to develop site-specific data in any context to carry out the impact assessment.

While calculating the embodied energy and emission of CO_2 it was found that some of the data such as paints, bitumen and waterproofing compound were not available in the Indian context. These have been adopted from the embodied energy of materials in New Zealand (Alcorn, 1998), since data on steel, cement etc. of the same source are similar to that of India.

1.5 STRUCTURE OF THE DISSERTATION

Chapter-1 is on the background of this dissertation. It has explained the aims, objectives and methodology adopted in this research. Chapter 2 is about literature survey. It has derived the domain of sustainable construction with reference to the researchers' and international institutions' views on sustainability. This chapter has also identified the need of an impact assessment tool and set the premise of this dissertation.

Chapter 3 has carried out an approximate estimate of funding required for supplying the basic minimum services in India in order to understand the scale of infrastructure needs. While this dissertation has been based the experience of primary school construction, chapter 3 has included housing and primary healthcare also in calculating the required funding. It may be noted that the construction technologies adopted in Andhra Pradesh Primary Education Project were based on the best practices in housing sector. The Secretary to the Ministry of Health and Family Welfare, Government of Orissa, participated in the primary school construction workshop convened at Hyderabad in 1996 and was influenced by the cost saving aspects. She initiated a similar programme on cost effective primary health centre construction in her state. Therefore, while this dissertation has been based on the experience of primary school construction, the assessment tool and the database on construction technologies could be used in housing and primary healthcare sector as well. Therefore, healthcare and housing have been included along with primary education while calculating the infrastructure shortage in India under the basic minimum services.

The domain of sustainable social infrastructure development has been established in chapter 4 based on chapter 2. However, that alone will not be able to ensure sustainability at activity level. Therefore, by using the data of Orissa healthcare building project, chapter 4 has demonstrated the impacts of construction technologies at grass root level within the domain of sustainable social infrastructure development. This chapter has emphasised on the need for data to carry out impact assessment. Chapter 4 has shown the domain of life cycle impacts of a building from planning, implementation, use and replacement stage and has explained the sustainable way to achieve it.

Chapter 5 has provided a detailed account of the Andhra Pradesh Primary Education Project. This chapter has carried out data analysis showing the impacts of different construction technologies on unit cost, labour intensity, money retained within the district, embodied no-renewable, renewable and waste energies. Chapter 5 also showed how the plan-forms, site conditions, etc., affected the impacts. The technological options identified in Ranga Reddy district gave an opportunity to the planners, architects, engineers and the Government to adopt sustainable systems in a context.

The primary school buildings (Andhra Pradesh) constructed in 1996 were examined in 1998 and rectifications were carried out in 2000. Chapter 6 has provided a detailed data analysis of the repair works that formed the basis for life cycle analysis of different roofing and walling systems. This chapter also discussed the justification for assuming the frequency of repair of different technological components of the schools. Chapter 5 and 6 have established that the experience and data of the Andhra Pradesh school construction have been a valid basis for developing an impact assessment tool.

Chapter 7, based on the issues discussed in chapter 2 to chapter 6, has developed a model for impact assessment. This chapter has included a new component in environmental parameters – CO_2 emission, which was not considered in Andhra Pradesh Primary Education Project owing to a lack of awareness on international agendas. Chapter 7 has identified the nine socio-economic and environmental parameters used in the model. Assuming the nine parameters as examination papers and considering different combinations of walling and roofing technologies as the students in a class, the model has calculated the scores by adopting index method.

Chapter 8 and chapter 9 have described the process of data collection and calculated the actual values for new construction of different roofing and walling systems in the Ranga Reddy district, Andhra Pradesh. These chapters have been kept in the main document of the dissertation (and not in the appendices) since the process of database development has been considered to be as important as the assessment tool.

Chapter 10 has demonstrated the impacts of different combinations of roofing and walling systems by assuming that 100 million rupees (£ 1.25 million) has been invested on school construction in a district as in the case of the District Primary Education Programme. The Andhra Pradesh database has been used for impact assessment. The assessment results for new construction have been analysed and presented in suitable formats to provide an overall picture of the impacts.

Chapter 11 has analysed the defects that occurred in different technologies adopted in Andhra Pradesh owing to ageing. It has explained the basis of determining the frequencies of maintenance-interventions. This chapter also provided data on recurring maintenance, which has been used for life cycle impact of construction technologies on socio-economic and environmental aspects. As in chapter 10, this chapter has also adopted the example of District Primary Education Programme and showed the life cycle impacts at district level assuming 50 years as the building life.

The main purpose of chapter 10 and chapter 11 was to give an idea to the decision makers on the scale of impacts. Both the chapters revealed that, while the quantities of the impacts under the nine parameters were necessary to have a realistic idea on the extent of impacts of the different technologies; they were not adequate for selecting the appropriate options. Therefore, chapter 12 has used the model developed in chapter 7 to find out the scores obtained by all combinations of roofing and walling systems used in Andhra Pradesh Primary Education Project. Chapter 12 has shown the effect of different weights on the final scores. This chapter has concluded by identifying the sustainable walling and roofing options in the context of Andhra Pradesh.

Chapter 13 began with a discussion on how the aims and objectives of the dissertation have been achieved. This was followed by reviewing of the assumptions and limitation. This chapter has then discussed the key findings and conclusions in the context of Ranga Reddy district. Then it has described this research in the context of others' works in the field. This has been followed by the discussion on the major contribution of this dissertation in Indian and wider context of sustainable development and construction. Chapter 13 has discussed the recommendations on the implementation of this research in the field of sustainable social infrastructure development in India. Finally the chapter has discussed the opportunities for future research envisaged by this dissertation. The post script has stated that the model developed in this dissertation has been used outside India (South Africa) successfully.

CHAPTER 2 LITERATURE SURVEY

2.1 THE ANDHRA PRADESH PRIMARY EDUCATION PROJECT AND ITS INFLUENCE

As mentioned in chapter 1, the author was appointed by DFID (India) to help the Government of Andhra Pradesh to construct cost effective schools within the State. The author conducted a research on what was available in India as cost effective technologies. While probing into what the state of art was in India, it was found that the Central Building Research Institute, Structural Engineering Research Centre, National Building Organisation, Building Materials and Technology Promotion Council, Housing and Urban Development Corporation and Non-Governmental Organisations such as Development Alternatives, Centre Of Science and Technology For Rural Development, etc., were claiming to supply affordable, cost effective, buildings. For example, the building centre at Quilon, Kerala, claimed that they were saving 30% cost (MOST, no date) over the conventional steel and cement-intensive systems. Based on that investigation demonstration school buildings were constructed at 29 sites using various walling, roofing and foundation technologies. The data of this project has been accurately documented and published as a handbook (Bonner and Das, 1996) called Vidyalayam to facilitate cost effective primary school construction in other programmes.

When Andhra Pradesh Primary Education Project was over (1996), a programme called District Primary Education Programme was initiated, which attempted to universalise elementary education in India. This was a Government of India funded programme in its 18 states with the financial assistance from many countries and loan from World Bank. This programme was influenced by Andhra Pradesh Primary Education Project experience, which is evident from a letter from the Ministry of Human Resource Development (D.O. No.16-2/97.District Primary Education Programme dated 4th August 1997). The letter to DFID acknowledged that Vidyalayam is a "*very useful*" publication and requested them to supply more books for their annual conference in Trivandrum - "*I would be grateful if you could give us another 200 copies for distribution in the workshop where engineers from state and district levels and consulting architects from District Primary Education Programme states would be attending*". Apart from the primary education sector, Vidyalayam was adopted in housing as well. Project Leader of Uttar Pradesh Academy of Administration requested DFID (ref 16/CDS/UDC/(4)-90-1/o/01/97, 23rd July 1997) asking for permission to use selected portion of Vidyalayam as study materials for their training programme on cost effective housing. The letter said - "*The contents of the handbook are* *very useful. We want to use some selected portions from the handbook in our training programmes as resource materials / background material".*

Realising that Vidyalayam was being widely used in many programmes, DFID Education Sector Group in India felt that it was necessary to evaluate the performance of the Andhra Pradesh Primary Education Project schools. The main point was to confirm whether the buildings were performing well over time and to check if there was any major problem with them which could be brought to the notice of the programmes based on Vidyalayam experience and database. DFID India appointed the National Council for Cement and Building Materials (NCCBM), a leading research institute in Delhi, and two specialists from Intermediate Technology Development Group (UK) to carry out the evaluation of the Andhra Pradesh Primary Education Project schools in November 1998. The evaluation report (basin news, 1999) revealed that the Andhra Pradesh Cost Effective Construction Technologies process demonstrated a wide range of design and technology options, which can effectively reduce the cost of delivering classroom space. The basin report on the evaluation also stated that *"it has also been instrumental in generating increased interest for the subject in the planning process of other education programmes across India by disseminating widely both the information generated by the project and support resources"* (basin news, 1999:17).

It may be noted that one of the most important programmes among the "other education programmes" mentioned in the evaluation report was District Primary Education Programme, which was implemented in 271 districts over 18 states, by spending approximately 27 billion rupees (£ 0.34 billion) on school infrastructure construction. The national evaluation of the construction component of District Primary Education Programme (Das et al, 2004) revealed that one of the major achievements of the programme was community based cost effective school construction. This programme is followed by Sarva Shiksha Abhiyan (Education for all) with the same objective of universalisation of primary education. Under this programme, 33% of total investment has been allocated for physical infrastructure construction. Based on past experience of cost effective construction in India, Sarva Shiksha Abhiyan has made community centred, cost effective and environment friendly school construction mandatory (GOI, 2005). The programme envisages that this community centred process will also improve building maintenance compared to the contractor-built schools.

Apart from these, the Orissa Health Project was also a direct influence of Andhra Pradesh Primary Education Project (Das, 1999). The Secretary to the Ministry of Health and Family Welfare, Orissa, visited the Andhra Pradesh schools in 1996 to explore if some of the technologies could be adopted in primary healthcare buildings in her state. The secretary then sent a request to DFID to provide technical assistance for constructing cost effective primary healthcare building construction in Orissa, which was completed in two years (1997-1999).

It appears that Andhra Pradesh Primary Education Project had considerable influences on the other programmes owing to its achievements such as cost effectiveness, wide range of technological and design options (basin news, 1999). More importantly, the database in Vidyalayam has been widely used in District Primary Education Programme and UNDP cyclone reconstruction programme (Das, 2001), etc., over the last eight years. As mentioned in chapter 1, this dissertation aims to develop an impact assessment tool for sustainable social infrastructure in India based on the Andhra Pradesh Primary Education Project experience. Hence, it is important to understand what sustainability means and what the domain of sustainable social infrastructure development is.

One of the most important issues is to understand the concept of sustainability. It has been noticed that in books, conferences, etc., people in general, do not clearly define what sustainability really means and what could be the way to it. In a recent International Conference on Sustainable Habitat Synergies in New Delhi, Pidcock (2005) presented a paper on the current state of sustainable approaches in Australia. However, she did not co-relate that in the Indian context. In the same conference, Lang (2005) stated that India has considerable experience in dealing with sustainable urban and architectural designing without explaining how he came to such conclusion. In the end Jon concluded by saying "we simply need to get going" which does not convey much.

The IInd International basin Conference in India (16th – 18th March 2004) was focused on Sustainable Habitat and Livelihoods for the Poor "strategic imperatives and practical solutions". If one reads page 25 of the proceedings (basin, 2004), which states the "Strategic Imperatives" and "Practical Measures", one would find that there is a lack of a concrete plan of action based on a defined "Sustainable goal" and the sub components that would help in achieving it. Therefore, the following section carries out a literature survey on sustainability

2.2 SUSTAINABILITY

It has been noticed that the words "sustainable" and "sustainability" are used frequently and the emphasis of research on these is remarkably high, e.g., the "Google search", showed that there are 6.69 million articles, information, net address, etc., on this topic (30th March 2005, 2:36 PM IST). The Government documents in India use this term quite often, e.g., the chapter 1 of the Tenth Five Year Plan (2002-2007) on "Overview" uses these two words six times in eleven pages. However, compared to the frequency of its use, the definition of sustainability is rarely candidly present or adequately described. For example, the chapter 1 of Tenth Plan does not explain as to what is meant by this word and how to go about achieving it. According to Dahl (1995), sustainable development has become the catch word of our decade, used and mis-used in many contexts. In the current development works, the discussions on sustainability thrive on unquestioned acceptance of this term, which could be explained with reference to Sarva Shiksha Abhiyan (Education for all), India's attempt to achieve the goal-2 of the Millennium Development Goals. The "Manual for Planning and Appraisal" (GOI, 2005) is meant for appraising the different States' proposal on Elementary Education by functional specialists. However, it does not clarify anything about sustainability in its introduction except mentioning only once "Sustainable Financing" (GOI, 2005:5). Although the document covers all the required components of sustainable development, the beneficiaries and the appraisers remain unaware of the overall mission because of lack of a clear definition and methodology to check whether the programme is progressing towards the sustainable primary education infrastructure. The Sarva Shiksha Abhiyan is a participatory and a completely "Bottom –up" approach (GOI, 2005:2) involving the stakeholders of elementary education at every level, where the term sustainability is uttered frequently in every meeting. As a result it has different meanings to different people.

According to Dahl (1995), sustainability has been notoriously difficult to define, not to mention to translate into other languages. If we are going to produce effective indicators of sustainable development, we must agree on what we are trying to indicate. However, before that we need to understand what sustainability means. We shall first examine the definitions of sustainability put forward by Brundtland (1987) and many other researchers in this field. This will be followed by a review of the various international level recommendations on sustainable development, such as, Agenda 21, Millennium Development Goals and DFID's Sustainable Livelihood Approach. All these views will then be the premise for sustainable development in India in the field of social infrastructure development.

In 1987 the United Nations Commission on Environment and Development drew attention to the fact that economic development often leads to deterioration, not an improvement, in the quality of people's lives (Brundtland, 1987). The Commission therefore called for a "Form of Sustainable Development", which meets the needs of the present without compromising the ability of future generations to meet their own needs. According to Brundtland (1987), development is not just about greater profits and higher standards of living for a minority. It should be about making life better for everyone and this should not involve destroying or recklessly using up our natural resources, nor should it involve polluting the environment. Brundtland's definition is supported by Lacasse (1999). According to him, sustainable development means the use of natural and physical resources that enables people and communities to provide for their immediate social, economic and cultural well being without compromising the ability of future generations to meet their needs.

There are criticisms of Brundtland's definition of sustainability, e.g., Drummond and Marsden (1999) criticize it by saying that this definition says very little about what sustainable development actually is or how it might be achieved. Bartlett (1998: 7) criticizes Brundtland by saying that *"Unfortunately, the definition (Brundtland, 1987) gives no hint regarding the courses of action that could be followed to meet the needs of the present, but which would not limit the ability of generations, throughout the distant future, to meet their own needs, even though it is obvious that non-renewable resources consumed now will not be available for consumption by future generations."* According to Bartlett (1998) starving people do not care about sustainability. If sustainability is to be achieved, the necessary leadership and resources must be supplied by people who are not starving.

Bartlett mentions about the three laws of human ecology given by Hardin (1993) and considers them to be fundamental, and need to be known and recognized by all who would speak of sustainability. The first two are - "We can never do merely one thing", "There's no away to throw to". The third says that the impact of any group or nation on the environment depends on the size of the population, the per-capita affluence, and the damage done by the technologies that are used in supplying the consumption. Hardin attributed this law to Ehrlich and Holdren (1971).

According to Fricker (2001), Veiderman (1995) has been the closest to an appropriate definition of sustainability, who stated that sustainability is a vision of the future that provides us with a road map and helps us focus our attention on a set of values and ethical and moral principles that should guide our actions. According to Viederman, there are three principles underlying the discourse on sustainability, viz., the humility principle, which recognises the limitations of human knowledge, the precautionary principle, which advocates caution when in doubt, and the reversibility principle, which requires us not to make any irreversible changes. All three appear equally important. However, the last point is more oriented towards a definite action plan than the other two and will help decision makers to stress on this issue while accepting any proposal for sustainable development.

Instead of adopting a formal definition of sustainability, Raynsford (1999:1) defines it as *"It is about ensuring a better quality of life for everyone, now and for generations to come"*. He sets out the vision for sustainable development built on four objectives of the UK Government's approach to sustainable development. The first point is to ensure that everyone lives in a clean and safe environment by initiating a social progress, which recognises the needs of everyone and reduces the harm to health caused by poverty, poor housing, unemployment and pollution. The second point is the protection of the environment both from the global threats and at local level, e.g., protect the things that people value such as wildlife, landscape and historic buildings. The third point is ensuring prudent and efficient use of natural resources and that renewables are developed, wherever possible, as alternatives to materials and fuels in limited supply. The fourth point is continuing to secure high and stable levels of employment together with continuing economic growth, so that every one can share in higher living standards and job opportunities. It will be seen later in this section that all these are responses to the Agenda 21, Millennium Development Goals, etc.

Plessis (1999) stated that, while there is little consensus about a definition for sustainable development, there are certain commonly accepted principles that can nonetheless be used to guide sustainable development. He grouped them under the three pillars of environmental, economic and social sustainability. A fourth overarching principle is that the sustainable development is a continuous process of dynamic balance. Similar to Plessis, Cole (1999) also states that the three dimensions of sustainability are environmental, social and economic. According to him it embraces all facets of human activities, e.g., industry, transportation, food production, etc. It is important to note that Cole (1999) admits that sustainability spans local actions through to redressing the major inequities that exist between developed and developing nations. He concludes that given the political and economic interdependencies wherein the actions of one nation profoundly affect others, the notion of 'sustainability' is perhaps only meaningful when applied at a global scale. As described above, Raynsford's (1999) opinion in this regard is in slight variation when he says that one of the important considerations in sustainable development is the protection of the environment both from global threats and at local level. It may be noted that impact at global scale can not be assessed if local levels impacts are not known.

Dahl (1995) observes that our society functions in a natural environment, uses resources, discharges wastes and emits harmful gases into the atmosphere. Therefore, one very important component of sustainability is the intimately interrelated and dependent human society with the natural systems. Having said that, Dahl opines that sustainable development implies a central focus on people. According to him, while this may seem anthropocentric, in the present context of the international debate on development and equity, any other approach could be considered morally indefensible. It is important to note that making sustainable development anthropocentric will indeed help in improving the environment by prudent use of natural resources with the growing awareness of the people and the community, which has been recommended by the Millennium Development Goals explained in the later part of this section.

Dahl cautions that there is a danger of using indicators to make value judgements about the content of development. Similarly, Plessis (1999) also states that sustainable development was also seen to imply certain qualitative issues about human aspirations, emotional well-being and social relationships. Dahl suggests that one way to express the concept of sustainability without falling into value judgements about development will be to produce "vector" indicators which basically show the direction of movement towards or away from a goal, and the speed of that movement. Such indicators will allow each country to define for itself how it imagines its ideal future sustainable society and then to report, for each indicator, whether it is making progress towards its own goal, and at what rate.

Human needs and aspirations change over time and affect the environment. In the recent past this has been rapid, particularly in India and China owing to their population increase. Plessis refers to Pearce (1996) and states that for the first time, it has been realized that sustainable development could be seen as 'a process instead of a fixed destination', Dahl (1995) states that for a dynamic process like the sustainable development, it is normal to have a moving target. This is a very important issue and the Government of India with its every five year plan should ideally review its targets and evaluate a new one depending upon the success and failure of the last period.

Fricker (2001) warns that with the current attitude of human nature, we may push the global physical and biological capacities to their very limits. It is important for us to think of sustainability in terms of justice, interdependence, sufficiency, choice and above all the meaning of life. Professor Teopfer Klaus, executive director United Nations, makes it emphatic in the panel discussion of a World Bank organized workshop in Delhi (TerraGreen, 2004). On the issue of poverty he opined that as long as the richest 20% of the world population continue to account for 86% of total personal consumption expenditure, it is unlikely that the poor will meet their aspirations of sustainable development.

An important issue has been raised by Fricker (2001) regarding monitoring our actions towards sustainability. The question is how do we know that we are heading towards the goal of sustainability? Fricker (2001) states that we have a better understanding of what is unsustainable rather than what is sustainable. Unsustainability is commonly seen as environmental (in its broad sense) degradation resulting from the increasing human population, affluence and technology. Since these impacts on the environment are all our own creations, their control is, in theory, within our capabilities. Like Fricker, Dahl (1995) also said that most of the present indicators of sustainability measure negative factors or pressures preventing sustainability. For example, we talk about environmental degradation owing to CO_2 emission. Dahl (1995) comes up with a concrete suggestion and says that since sustainability is itself difficult to define and the indicators measure negative factors preventing sustainability, vector measures will allow the countries to report, for instance, the progress they are making in reducing damaging activities, even if they have not yet defined clear goals for sustainability.

In 1992 the United Nations held a conference on Environment and Development (The Earth Summit) in Rio de Janeiro where the nations of the world agreed on an action plan for the next century, AGENDA 21, which recognises that humans depend on the Earth to sustain life and there are linkages between human activity and environmental issues. Agenda 21 is a comprehensive plan of action to be taken globally, nationally and locally by organizations of the United Nations System, Governments, and major groups in every area, in which, human activities have impacts on the environment. According to the Agenda 21, all States and all people shall cooperate in the essential task of eradicating poverty as an indispensable requirement for sustainable development. The conference recommended that people should be involved in planning developments for their own communities if such developments are to be sustainable (Seafield Research & Development Services, no date). People are entitled to a healthy and productive life in harmony with nature.

According to the "Report of the United Nations Conference on Environment and Development" (1992 updated:1999) the Environmental Impact Assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment. Environmental issues are best handled with the participation of all concerned citizens, at the relevant level. States shall facilitate and encourage public awareness and participation by making infomation widely available.

According to Perrings (1994), the central assumption of Agenda 21 is that sustainable development is divisible and hence, sustainability of the component parts could be devised in different sectors, resource categories and levels of society. Perrings (1994) says that "sustainable livelihood" and "environmentally sound technology" are the subcategories of the general concepts "sustainable development" and "environmental soundness" According to him, this requires not only the sustainable development of all communities within a society, but also the sustainable livelihood of individuals within those communities and the environmental soundness of each process. However, it will be unrealistic to try to achieve sustainability in each and every micro level component individually. What one has to keep in mind is the importance of maintaining the resilience of ecological and economic systems at appropriate levels, e.g., thinking of the behaviour at community level rather than of individuals within the community. Similarly, if one thinks of the ecological systems rather than the component organisms of those systems, one comes closer to an operational concept. He highlights the importance of incentives, the level of activity and distribution of income for the achievement and maintenance of that resilience.

According to Chen and Chambers (1999), China plays an important role in maintaining world sustainability. By reviewing China's response to Agenda 21, they concluded that the current stage of economic development in China provides an opportunity to incorporate environmental provisions into the national development strategies from a relatively early stage. However, at present, China's Agenda 21 remains only a visionary concept, which lacks a comprehensive policy framework and realistic implementation measurements.

India's response to Agenda 21 is in the social, economic, environmental, institutional sectors. According to the Government of India (GOI, 1999), almost all the Ministries are involved in achieving the Agenda 21 objectives. However, as mentioned earlier, the documents of the programmes, such as, Sarva Shiksha Abhiyan with an infrastructure construction component do not show any evidence of the kind of approaches suggested by Dahl (1995), Plessis (1999), Perrings (1994), etc. There is an urgent need for the beneficiaries and the Government officials to adopt a common sustainable goal so that they can evaluate and monitor their progress.

In September 2000, the member states of the United Nations unanimously adopted the Millennium Development Goals. These Goals commit the international community to an expanded vision of development, one that vigorously promotes human development as the key to sustaining social and economic progress in all countries, and recognizes the importance of creating a global partnership for development. The goals have been commonly accepted as a framework for measuring development progress. Many of the targets of the Millennium Development Goals were first set out by international conferences and summits held in the 1990s. The eight goals are –

- eradicate extreme poverty and hunger (Goal 1),

- achieve universal primary education (Goal 2),
- promote gender equality and empower women (Goal 3),
- reduce child mortality (Goal 4),
- improve maternal health (Goal 5),
- combat HIV/AIDS, malaria, and other diseases (Goal 6),
- ensure environmental sustainability (Goal 7),
- develop a global partnership for development (Goal 8).

This dissertation will show how the financial pressure on the infrastructure component of goal 2 could be reduced by using cost effective construction technologies. This will result in creation of more learning space than the conventional cement and steel intensive systems can provide. The dissertation will also show that supplying the infrastructure component of the goal-2 could be viewed as an opportunity for addressing the goal-1, by adopting labour intensive systems. However, while attempting to reduce cost and increase employment opportunities, the materials and methods should not be a threat to the environment, which falls under goal-7.

One of the goals has been reducing the proportion of people living on less than US $1 a day to half the 1990 level by 2015-from 28.3% of all people in low and middle income economies to 14.2%. Per capita consumption of $1 a day represents a minimum standard of living, yet more than a billion people live on less than that. In middle-income economies, a poverty line of $2 is closer to the practical minimum. In 2000 an estimated 2.7 billion people were living on less than $2 a day - more than half the population in the developing world (The Millennium Development Goals, 2003).

The Millennium Development Goals emphasized that the principles of sustainable development should be integrated into country policies and programmes and reverse the loss of environmental resources. The environment provides goods and services that sustain human development so we must ensure that development sustains the environment. Better natural resource management will increase the income and nutrition of the common people. The target time for achieving the Millennium Development Goals is by 2015.

The Millennium Development Goals state that there has been extensive use of fossil fuels in recent decades that have increased carbon dioxide emissions – a major contributor to global warming. Out of estimated 6 to 7 billion tons of carbon dioxide released each year by human activities, some 2 billion tons are absorbed by oceans, and another 1.5 to 2.5 billion by plants, with the rest released in the atmosphere. The level of carbon dioxide in the atmosphere is up by some 30% since the beginning of the industrial revolution. According to the Inter-Governmental

Panel on Climate Change (IPCC, 2001), the rate and duration of warming in the 20^{th} century are unprecedented in the past thousand years – the global average surface temperature has increased by about 0.6 degrees Celsius. The warming is expected to continue, with increases projected to be in the range of 1.4 to 5.8 degrees Celsius between 1990 and 2100.

Sen (2004) shows in his presentation that the Tenth Five Year Plan has responded to all the eight goals of Millennium Development Goals by taking actions under each and every target. Deolalikar (2004), reports that a number of interventions including economic growth, improved infrastructure has been undertaken as Indian response to the Millennium Development Goals. However, according to Deolalikar, currently there is no system for monitoring progress toward attainment of goals at the sub-national level.

The UK Government's White Paper on International Development (DFID, 1997) committed their Department For International Development to supporting policies and actions which promote sustainable livelihoods, better education, health and opportunities for poor people; protection and better management of the natural and physical environment. This will help to create a supportive social, physical and institutional environment for poverty elimination. Department For International Development's aim is to eliminate poverty in poorer countries. Specifically, they have signed up to the International Development Target of reducing by one-half the proportion of people living in extreme poverty by 2015.

In the above paragraph the term "sustainable livelihoods" needs clarification. According to "An Approach to Sustainable Livelihoods" (DFID, 1999a) the Development agencies traditionally have relied heavily on measurement of economic factors (income and productive assets such as land and cattle) to assess poverty. These programmes thus focused primarily on increasing income and assets. However, the well-being of poor households is influenced by interactions among economic, social, natural resource and political factors. This knowledge led several agencies to adopt a Sustainable Livelihoods Approach to improve their poverty reduction programmes.

Sustainability has many dimensions, all of which are important to the sustainable livelihoods approach. The word 'livelihood' can be used in many different ways. The broad notion of livelihoods understood by the Department For International Development (DFID, 1999a) is based on the definition by Chambers and Conway (1992). According to that, a livelihood comprises of capabilities, assets (including both material and social resources) and activities. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base. Livelihoods are sustainable when they are resilient in the face of external shocks and stresses; not dependent upon external support (or if they are, this support itself should be economically and institutionally sustainable). It should maintain the long-term productivity of natural resources; and not undermine the livelihoods of, or compromise the livelihood options open to, others.

Economic sustainability is achieved when a given level of expenditure can be maintained over time. In the context of the livelihoods of the poor, economic sustainability is achieved if a baseline level of economic welfare can be achieved, which is likely to be situation-specific. However, it can be thought of in terms of the 'dollar-a-day' (US $) of the Millennium Development Goals. Apart from that, environmental sustainability is achieved when the productivity of life-supporting natural resources is conserved or enhanced for use by future generations. According to DFID's Sustainable Livelihood Approach, people should be at the centre of development.

The above discussion on sustainability encompasses all human activities consuming natural resources and affecting land, water and air. As mentioned in chapter 1, one of the aims of this dissertation is to provide an assessment tool for the decision makers in the context of sustainable social infrastructure development such as primary school construction. Construction is a major human activity. Therefore, above discussion on sustainability is also the context of sustainable construction. It is important to note that construction industry has a major role to play (Raynsford, 1999). According to Raynsford there is increasing evidence that the industry not only recognises that but is preparing to play its role. However, Lacasse (1999) does not seem to be happy about the construction industries' current trend. He stated that the industry must examine certain consequences in the process of achieving sustainable development since it consumes a considerable amount of natural and physical resources and thus has a significant impact on the environment. He states that current trend of building design, engineering methods, manufacturing technologies and construction techniques need to be altered to accommodate requirements for sustainable construction. In this context, Harmaajärvi (2000) suggests that an ecologically sustainable area can be described as an area that requires the supply of as little energy and raw materials as possible (especially non-renewable materials) and that produces the minimum harmful emission and wastes from all the buildings and operating processes on a life cycle basis. A sustainable area should also offer people a good living environment and be economically affordable.

Ofori (1998) refers to Tisdell (1985) and states that sustainability in resource use is critical in developing countries. More of their people rely on natural resources at the basic level. He states that according to Gupta (1993) 40 million people in rural India rely on the forests for their livelihood, which puts the issue of the use of timber in construction and its relationship with deforestation into perspective.

This section on the researchers' views on sustainability and the international guidelines in this regard tends to suggest that the three pillars of sustainable development are social, economic and environmental. However, identifying the three pillars of sustainability alone will not lead to sustainable social infrastructure development in India. We have to understand what are we supposed to do under these headings. As a starting point, it may be reasonable to adopt Perrings' (1994) suggestion on sustainability. According to him, the central assumption of Agenda 21 is that sustainable development is divisible and sustainability of the component parts could be devised in different sectors of the society. This may be derived from Table 2.1 showing various issues raised by different researchers and institutes in the domain of sustainability. The issues have been put under the headings - social, economic and environmental. It may be noted that Plessis (1999) refers to Barbier (1987) and states that it is generally accepted that sustainable development attempts to maximize goal achievement across the three systems, viz., the biological/ecological resource system, the economic system and the social system.

The author of this dissertation has summarised the observations put forward by the researchers and the institutions (discussed so far) in Table 2.1. The suggestions on sustainable development by the different researchers and the institutions have been tabulated row-wise in Table 2.1. Each of such suggestions has been categorized under three columns "Social", "Economic" and "Environmental". The last row (shaded) in Table 2.1 is the author's interpretation based on the patterns in the columns "Social", "Economic" and "Environmental".

Affordable shelter, healthcare and primary education facilities in the shaded row under column "Social" may be possible by reducing unit cost of construction. Making the development programmes anthropocentric will render justice and equity for the people and might reduce cost of construction, since the communities know their local contexts. The shaded row under the column "Economic" in Table 2.1 can be addressed by adopting labour-intensive and local materials-based construction technologies to create direct livelihood and by creating income multiplier effect. The shaded row under the column "Environmental" can be addressed by keeping in mind that while selecting technologies that are low cost and livelihood generating, the impact on the environment is the least. Construction results in depletion of non-renewable and renewable energies and CO_2 emission.

Table 2.1 Summary of different researchers' and the International Institutes' suggestions on the possible domain of sustainable social infrastructure development.

	The three pillars of sustainability		
Sources	**Social**	**Economic**	**Environmental**
Brundtland (1987)	Making life better for everyone		Reduce consumption of natural resources and pollution
Bartlett (1998)		Starving people do not care about sustainability	
Raynsford (1999)	It is about ensuring a better quality of life for everyone- eliminate poor housing,	Reduce poverty, unemployment and continuing economic growth	Prudent use of natural resources, emphasise use of renewables & reduce pollution.
Fricker (2001)	Sustainability in terms of justice, interdependence, sufficiency, choice & meaning of life.		Human population, affluence and technology stresses on ecological and global limits.
Dahl (1995)	Development honouring equity and with people in the centre		
AGENDA 21	The human being is entitled to a healthy and productive life	Eradicating poverty as an indispensable requirement for sustainable development.	States to facilitate and encourage public awareness and participation in environmental issues
Perrings (1994)		Sustainable livelihood of individuals	Assessing the environmental soundness of each process.
Lacasse (1998)			Construction industry has a significant impact on the environment.
Millennium Development Goals (last updated 2003)		Reduce number of people earning less than $1 a day from 28.3% (1990) to 14.2% (2015)	Reduce carbon dioxide emissions – a major contributor to global warming.
DFID's Sustainable Livelihood Approach (DFID, 1999a)	- People at the centre of development - Better education, health and opportunities for poor people.	Reduce proportion of people living on less than $1 a day from 28.3% (1990) to 14.2% (2015)	Better management of the natural and physical environment. Livelihood not undermining the natural resource base.

Table 2.1 Continued...

	The three pillars of sustainability		
Sources	**Social**	**Economic**	**Environmental**
Cole (1999)			Environment is very important in sustainability
Harmaajärvi (2000)	Create good living environment and be affordable economically.		Minimum energy and raw materials (especially non renewable) produce minimum harmful emission and wastes
The following issues in construction sector have been summarised by the author after studying the pattern in column "Social", "Economic" and "Environmental"			
Issues in the construction sector.	**Community centred development** **Providing affordable shelter, primary healthcare and education facilities**	**View construction as an employment opportunity.** **Use labour intensive systems**	**Reduce embodied non renewable and renewable energy** **Increase use of waste** **Reduce CO_2 emission**

In order to have an in-depth understanding of the issues of sustainable construction shown in the shaded row of Table 2.1, it is necessary to carryout a detailed investigation on cost reduction, construction as an opportunity for employment opportunities and a threat to environment. It is also important to carry out a detailed study on life cycle analysis of the socio-economic and environmental impacts of construction.

2.3 ISSUES RELATED TO SUSTAINABLE CONSTRUCTION

2.3.1 Cost Reduction in Construction

<u>MATERIALS</u>

In the domain of sustainable construction in India, reduction in unit cost of construction (rupees per square metre) appears to be a very important component. In the context of housing, Tiwari et al (1996) stated that the problem in India is of scarcity of basic resources such as land, building materials, skilled labour, etc. Given the existing cost structure, there is no prospect for the overwhelming majority of people, of being able to have houses satisfying their most basic requirements. However, the database of "Vidyalayam" (Bonner and Das, 1996) tends to suggest that there is some hope in this regard. Therefore, the issues in the last row of column "Social" in Table 2.1 can be addressed by exploring possibilities of cost reduction without compromising durability.

According to the UNCHS (1991) report, the developing countries are facing severe problems with regard to the supply of building materials. In most of the developing countries, building materials industries have not only failed to cope with the rising demand but the gap between the demand for building materials and the domestic capacity for production has widened further in recent years. This view is supported by recent studies in India as well. According to research conducted by the Building Materials Technology Promotion Council and Centre for Symbiosis of Technology, Environment and Management (BMTPC and STEM, 2000), there is a need for 173 million tons of cement and 600 billion bricks in India for the period 2001-2006. Based on the limited infomation available on the Indian brick industry, Maithel and Uma (2000) reported that more than 100,000 kilns produce about 80 to100 billion bricks per year. To increase the brick production from 100 billion (in 2000) to 600 billion in 2006 appears to be impossible. There is a need for alternatives to burnt clay bricks.

According to Deb (1994), research and development efforts in India during the last decades have focused on bricks, cement, steel and clay only. Deb states that cement based building products will probably continue to dominate the building industry for years to come. However, optimising or minimising its use in building can be achieved. It is important to note that Deb's article was published in 1994 and the DFID funded Andhra Pradesh Primary Education Project on cost effective construction technologies was initiated in 1994 and completed in 1996. The project has demonstrated that alternative building materials can save cost compared to the conventional solid brick wall. Andhra Pradesh Primary Education Project was virtually the kind of experiment which Deb has indicated.

In the context of shortages of building materials, UNCHS (1991) observed that there has been a growing recognition in developing countries that the small-scale sector holds the key to increased productivity in building materials industry. The inherent flexibility of small scale operations to cope with the volatile and shifting demands and their ability to take best advantage of available factors of production in developing countries are the main sources of their strength.

According to the UNCHS (1991) report, most of the developing countries are endowed with abundant natural resources, which can meet the demand for basic building materials. For example most countries in Africa have extensive deposits of limestone, gypsum and pozzolana that are sufficient to meet local demands for binder materials. Yet much of these natural resources currently remain unexploited in most developing countries. The report further states that an important factor that has contributed to this situation is the inability of building materials industries in developing countries to have access to technologies that could exploit the natural resources to increase the supply of building materials required by the construction sector. Recent technological innovations on building products and processes, e.g., a variety of roofing tiles of different sizes and shapes, L-panel roofing, fibre reinforced cement corrugated sheets, ferrocement construction, etc., provide excellent prospects for rejuvenating the small scale and informal sector of the industry and thus significantly improving the supply of basic building materials at affordable prices for low income groups.

According to the UNCHS (1991) report, building materials constitute about 70% of the total cost of construction in developing counties. For many basic building materials, e.g., bricks, cement lime and variety of pozzolanas, energy accounts for a large part of their costs. For some materials it may be as high as about 60% of their costs. Energy efficient technologies can therefore significantly reduce the cost of production of these materials. With some notable exceptions (e.g. China and India) developing countries have, in general, failed to stimulate an indigenous supply of technologies that can replace or upgrade traditional technologies in the building-materials industry (UNCHS, 1991).

ROLE OF COST EFFECTIVE TECHNOLOGIES

Housing and Urban Development Corporation introduced a building centre movement in India with 624 building centres spread across the country (HUDCO, 2002). The main objective of building centre has been to transfer cost effective technologies from the lab to land (MOST, no date), which will give access to the people to build their shelter. Keswani (1997) appraised the building centre movement by the Housing and Urban Development Corporation. He carried out a very limited investigation by visiting only three of the building centres in India, viz., Nizamuddin Building Centre of Delhi, Nirmithi Kendra in Kerala and Anagpur building centre at Haryana. According to Keswani, the building centre at Nizamuddin has been functioning as the research, training and developmental centre of the Housing and Urban Development Corporation at the national level. The Nirmithi Kendra at Quilon in Kerala, India often supplements the efforts of organisations such as Centre Of Science and Technology for Rural Development that trains masons, artisans, carpenters, architects and engineers in low cost construction practices. The Anangpur building centre carries out building materials research, develops cost effective technologies, provides on-site training for masons, architects, engineers participating in any of its projects and prepares documentation of its works for further dissemination.

Keswani (1997) opines that, although there are reasons to consider the building centre programme successful, the progress is rather slow. Several building centres have been established all over India, but not all of them have developed enough to achieve all the objectives laid out for the building centre. According to Keswani (1997), some people continue to think that Government of India must give more subsidies to solve the housing problem. He thinks that this would incapacitate the people. Keswani (1997) argues that the Government's role could change from being provider to becoming facilitator.

According to Keswani (1997), the implementing organisations in India that have been more successful than others in the field of low cost housing are the Non Governmental Organisations and also some private entrepreneurs. Perhaps the role of the Government, in the present times, should include designing strategies and formulating policies in close association with these grass-root level institutions. Effective response to affordable and adequate housing in India may result from better cooperation between Government and non Government institutions. According to Keswani (1997), the building centres have demonstrated that alternative construction technologies can bring down cost of construction. Keswani (1997) does not mention about building centre movement in any other country.

The above sections indicate that cost of construction can be reduced by using alternative materials and technologies. It is important to note that one can also save on cost by reducing the wastage at construction sites. According to Formoso et al (2002), waste in the construction industry is important. He states that to many people, the notion of waste is directly associated with the debris removed from the site and disposed off in landfills. The main reason for this relatively narrow view of waste is perhaps the fact that it is easy to see and measure. Other types of material waste beyond debris also need to be considered. Skoyles (1976) makes a distinction between direct and indirect material waste. Direct waste consists of a complete loss of materials owing to the fact that they are irreparably damaged or simply lost. In this case, the wastage usually needs to be removed from the site. By contrast, indirect waste occurs when materials are not physically lost; causing only a monetary loss— for example, waste owing to concrete slab being thicker than specified by the structural design. While this appears to be an important issue, according to Formoso et al (2002) the literature review indicated that the availability of data on material waste in the building industry was scarce. They further state that the number of empirical studies in different countries is small, and except for Skoyles (1976), all of them investigated a fairly limited number of materials in a few construction sites.

According to Formoso et al (2002), the concept of waste is directly associated with the use of resources that do not add value to the final product. Therefore the detrimental effect of waste on cost, energy and emission could be to some extent eliminated by training of the construction workers and the site managers. Unfortunately, we do not find data on wastage at construction sites in India and hence, this has been excluded from the study area. However, it is an important component of cost saving and hence, future data collection should emphasise this.

Let us now look at what Andhra Pradesh Primary Education Project can offer in the light of local materials, small scale manufacturing and above all cost reduction by adopting alternative technologies. The primary schools in Andhra Pradesh in 1995-96 achieved cost reduction by eliminating over specifications that was used conventionally, e.g., the random rubble foundation wall width was reduced from 450 mm to 380 mm. Similarly, 345 mm thick clamp bond brick wall was reduced to 230 mm by using kiln burnt bricks. While each brick of the latter was more expensive than the former, the savings in total number of bricks, reduced cement consumption and labour cost made the 230 mm kiln burnt brick masonry more economic than the clamp bond brick wall. The use of filler slab (described in Appendix IV) partially replaced cement concrete by light weight inexpensive clay tiles. This reduced the self weight, which lowered the consumption of steel thereby making filler slab more economic than solid reinforced cement concrete slab.

2.3.2 Construction - an Opportunity for Poverty Reduction

According to Der-Petrossian (1999), one tenth of the global economy is devoted to construction and operation of residential and office buildings. Therefore, it is an important industry for employment generation. Moavenzadeh (1987) recognised that domestic construction of shelter and infrastructure in developing countries has the potential to contribute to development. According to him, in developing countries, the contribution of construction to gross domestic product (GDP) is typically 3% to 8%. In most of the developing countries, construction contributes 40%-70% of Gross Fixed Capital Formation. In general construction is an opportunity for both developed and developing countries, e.g., in 2003, the construction industry employed 6.6% of Britain's total work force and generated about 10% of GDP (The Concrete Centre, 2004). According to Moavenzadeh (1987), on an average, construction accounts for 5% of the employment in developing nations. In southern Europe and many of the industrialised economies, the contribution is higher – 7% to 9%. He further states that the large number of unskilled workers in the construction industry gives it a great capacity to absorb labour, especially from the agricultural sector. In the low income African countries construction is the most important sector in this respect. Moavenzadeh (1987) states that studies by the World Bank have shown that 60 developing countries would be benefited from the greater use of labour based construction.

According to the Tenth Five Year Plan (2002-07) of India, the share of construction sector in gross domestic product (GDP), which was 5.4% in 1970-71, came down to 4.4% in 1990-91. Subsequently it picked up and stood at 5.1% in 1999-2000. The share of the construction sector in total gross fixed capital formation (GCF) came down from 60% in 1970-71 to 34% in 1990-91. Thereafter, it increased to 48% in 1993-94 and stood at 44% in 1999-2000. Clearly, there has been a decline in the share of construction sector in the GDP and capital formation. The main reason for this according to the Tenth Five Year Plan was reduced Government spending on physical infrastructure in the last decade owing to fiscal constraints.

EMPLOYMENT AND CONSTRUCTION INDUSTRY

According to the Tenth Five Year Plan (2002-07) of the Planning Commission, Government of India, the construction sector is one of the largest employers in the country. The main advantage of the construction sector in employment generation lies in the fact that it (i) absorbs rural labour and unskilled workers (in addition to semi-skilled and some skilled); (ii) provides opportunity for seasonal employment thereby supplementing workers' income from farming; and (iii) permits large-scale participation of women workers. In 1999-2000, it employed 17.62 million workers, a rise of 6 million over 1993-94. The sector also recorded the highest growth rate in generation of jobs in the last two decades, doubling its share in total employment. Investment on construction leads to employment opportunities for construction related people. Tiwari et al (1996) stated that according to an estimate by the National Buildings Organisation, Government of India, an investment of 10 million rupees in building construction would generate on-site employment of 923 man-years and off-site employment of 1477 man-years. Tiwari et al states that in a typical construction activity around 33% is spent on labour. However, while stating these, Parikh et al (1993) do not mention the year of the estimate, neither did they mention the number of working days considered per man-year. Therefore, it is important to investigate whether by using local materials and labour intensive technologies, the employment opportunities mentioned above can be increased compared to the present situation.

MATERIALS AND EMPLOYMENT

In the context of investment on habitat and employment generation, Klaassen et al (1987) stressed that the choice of materials is very important for the creation of direct employment. The choice of materials also largely determines, through backward linkages, the creation of indirect employment. The effects are most significant in the building materials sector, but other sectors also benefit. According to Klaassen et al (1987), the backward linkages of the habitat sector are higher than those of most other sectors. Less indirect employment will be generated if more materials are imported and it will hardly profit domestic sector. Klaassen et al (1987) state that the indirect employment effects of an expansion of cement and steel intensive buildings will be below those of an expansion achieved with the intensive use of indigenous materials such as brick and wood.

LABOUR INTENSIVE TECHNOLOGIES

We will start this section with the views of Watermeyer (1993). He distinguishes between labour-based and labour-intensive construction. According to him, labour-intensive construction implies merely the use of as much labour as possible and is usually implemented in practice by substituting men for machine. The labour-based construction, however, aims at changing the technology employed in the construction process so as to make it appropriate for manual construction methods, thereby providing employment and training opportunities for both unskilled and semi-skilled labour. The emphasis in labour-based construction is on employment, training and development, whilst ensuring that the cost and quality are comparable with those of plant-based construction. Labour-based construction methods necessitate the complete reappraisal of design and construction techniques in order to find solutions appropriate for manual methods. However, in Indian context, the term "labour-intensive" is used for what Watermeyer (1993) defined as "labour-based". In the DFID funded projects in Andhra Pradesh and Orissa, the term "labour-intensive" was adopted, because it was commonly used in the Government engineering departments. Therefore, this dissertation will use "labour-intensive" for "labour-based".

Construction as an opportunity for employment is to be understood in terms of different skill levels of the workers available in a context. According to Moavenzadeh (1987), the developing countries have a higher percentage of unskilled workers than in developed countries. Similarly Watermeyer (1993) states that under-developed communities possess only one resource – labour, which is generally unskilled and untrapped. According to him, the labour content of a construction project can be increased by substituting unskilled men for machine. However, such increase in employment is temporary and such a change in construction practice will not equip people to become skilled so that they could be self-employed or qualify them for formal employment. The resources of under-developed communities will, therefore, remain un-enhanced. Watermeyer (1993) suggests that a community can derive the maximum benefit from construction projects – i) if they are structured so as to create employment opportunities, ii) promote community participation, iii) impart technical skills to the unskilled and semi-skilled sector of the community, iv) transfer administrative, commercial and managerial skills, v) retain, as far as possible, the funds expended on the project within the community and vi) develop contractors and entrepreneurs from amongst the local community. Clearly, the simple substitution of humans for machine will not satisfy many of the above criteria.

While the attempt to eventually develop skilled construction workers appears to be logical for achieving enhanced human resources, there are problems right now. According to Moavenzadeh (1987), ensuring an adequate supply of skilled construction workers is extremely difficult for many developing countries for several reasons. To begin with, he says that low monetary value is attached to construction labour relative to other sectors. The agricultural sector draws large number of labourers away from construction at critical periods. For example, Sha and Jiang (2003) report that the overwhelming majority of employees in China's building sector are labourers from rural areas. They account for 90% of the workforce on the production in construction projects. Many construction projects are interrupted in the farming season, e.g., May and September in Northern China, when the labourers from the rural areas go home for reaping and sowing. The Tenth Five Year Plan (2002-07) of the Planning Commission, Government of India, states that the Indian construction industry is characterized by the predominance of migratory and unskilled labour. Therefore, there is a need to expand the training and skill certification programmes. Tenth Five Year Plan reports that to encourage such training, incentives may be provided to contractors for funding the skill upgrading of construction workers. However, there is no institutional framework to impart training at the worker's level, barring a few initiatives taken by the Construction Industry Development Council (CIDC) and large construction companies such as Larsen and Turbo. Apart from that, the Andhra Pradesh and Orissa experiences revealed that the cost of training is also a barrier for masons' training.

Another important point in this regard is the scarcity of the skilled workers, since by tradition, the major means of acquiring skill in developing countries is through informal training on the job or though apprenticeship (Moavenzadeh, 1987). According to Jayawardane and Gunawardena (1998), over 80% of the construction workers in Sri Lanka are informally trained, and that a large percentage require further training either in their own or a new trade. However, by creating employment alone will not solve the problems. Moavenzadeh (1987) states that on the job training produces at best semi-skilled workers with project specific abilities. He also states that implementing formal training has been difficult. Construction firms are unwilling to invest in such programmes since the newly skilled workers were under no obligation to the firm that paid for their training and might leave for jobs elsewhere. According to Moavenzadeh, the public sector is expected to provide training programmes but most of these programmes have been unsuccessful. Apart from these, in many developing countries there is lack of job opportunity for the skilled masons. Jayawardane and Gunawardena (1998) report that over 60% of the skilled work force in Sri Lanka is not fully utilized, owing to lack of full time employment. The problem of funding for training of the construction workers is a separate subject and hence, will be excluded from this dissertation. However, the use of labour-intensive technologies is expected to increase the individual level wealth by creating round the year employment. This may enable them to save money after their domestic consumption and part of the training cost could be paid by the masons. However, this will take place only if they are convinced that the training will be financially beneficial for them. In any case, part funding by the industry will always be necessary for formal training.

In India it may be reasonable to adopt Watermeyer's (1993) view of increasing the employment opportunities in the construction sector. He states that what is required is a radical departure from the established approach to construction involving not only a change in the construction method, but also the construction process. Depending upon the situation in a context, decision making could be done to suit the local needs. In rural India there are a large number of agricultural labourers who engage themselves in construction activities in non-agriculture seasons (Tenth Five Year Plan, 2002-2007). Therefore, unskilled and semi-skilled labour-intensive systems may be adopted in rural construction projects. However, in the urban and semi-urban areas, there may be a need for promoting skilled and semi-skilled intensive technologies because of the availability of these types of skills. "Vidyalayam" (Bonner, Das, 1996) provides database for various options of labour-intensive construction technologies, which could be adopted for decision making in this regard depending upon the materials and type of skills available in different contexts.

MAINTENANCE AS AN OPPORTUNITY FOR EMPLOYMENT GENERATION

An important issue has been raised by Moavenzadeh (1987) regarding maintenance of buildings. He says that, developing countries have always a low priority for repair and maintenance. In developing countries maintenance generally accounts for less than 10% of the total construction cost as opposed to 25%-40% in developed nations. The demand for repair and maintenance provides a substantial market for contractors and suppliers of building materials. Moavenzadeh (1987) states that visits to many developing countries confirm that facilities are simply not being maintained. Traditionally maintenance of buildings has been viewed as liability in India owing to fund shortage (Das, 2000).

INCOME-MULTIPLIER EFFECT

The use of labour-intensive technologies based on local materials will give rise to accumulation of higher amount of money to the construction related people in a locality, than the cement and steel intensive systems. This is likely to lead to the income multiplier effect. Klaassen et al (1987) while discussing income multiplier effect states that once employment has been created on the site, indirect employment ensues from the need for materials and other requirements. The resulting increase in employment in turn generates second-order employment. Thus an investment creates various rounds of employment generation and consequent increases of income. The total income finally created is a multiple of the initial investment – the income multiplier.

Tipple (1992) has described this effect in the context of housing. According to him, the number of dollars and income generated within the country through the expenditure of US $1 on house building is termed the income multiplier. It means that if US $1 is spent on wages for a labourer, who then spends it on locally produced food (through the production of which other local people have earned their livings), the income multiplier will be higher than if the US $1 were spent on imported steel. An aggregate of all such spending, and its income effect within the country, is called an income multiplier (Tipple, 1992).

According to UNCHS/ILO (1995), if a shelter investment involves capital-intensive technology and the workers spend their income on imported goods, or taxes, or do not spend but save, the multiplier is likely to be close to 1. If the technology is labour-intensive and the workers consume only local produce, do not save, nor pay tax, leakage as the money circulates would be lower and the multiplier would probably be much higher than two. A similar figure has been suggested by Klaassen et al (1987). According to them, in general, the multiplier for habitat investments has been shown to be quite high compared to those of other sectors. Estimates for such countries as Colombia, India, Korea, Mexico and Pakistan all resulted in a figure of about two, the explanation being the usually lower import content of habitat outlays compared with those of other sectors. Moreover the habitat sector is relatively labour-intensive and unskilled labour generally tends to save relatively little. Finally income taxes are comparatively low for the lower income brackets concerned. Therefore, it is reasonable to adopt the value of two for income multiplier effect in this dissertation.

2.3.3 Construction - a Threat to the Environment

As evident in the section on sustainability, the environmental damage owing to human activities is under scrutiny. In this section we will examine this issue of sustainable development in the context of the construction industry. According to Lippiatt (1999), building construction consumes 40% of raw stone, gravel and sand used globally each year, and 25% of the raw timber. Buildings also account for 40% of the energy and 16% of the water used annually worldwide. According to Der-Petrossian (1999), one sixth to one half of the world's major resources (energy being the most crucial one) are consumed by construction and construction related industries.

According to Chen and Chambers (1999), the environmental impacts of the construction industry are extensive, particularly in developing countries. We shall examine this situation in China and

India because of their increased human activities owing to the population explosion compared to the rest of the world. Chen and Chambers observe that, although efforts in China have been made in terms of innovation of solid brick, research on passive solar-energy-heating buildings, improvement of earth buildings and development of ecological villages, the progress is far from satisfactory. The built-in defects of the economic system, lack of an effective legal system, lack of public awareness and Government bureaucracy contribute to the difficulty of putting the vision of sustainable construction into practice. According to Chen and Chambers (1999), China's sustainable construction is still at its primary stage.

Verma (2000) observes that, recently there has been an increased awareness about environmental protection in India. However, the Tenth Plan admits that the Indian development strategies have not been sensitive to the ecological issues, although its importance has long been recognised. Deb (1994) refers to the 1980 index of construction cost at national level (urban centres in India) and states that the material component was 72.34%, from which he concluded that the critical area of the Indian construction industry is building materials. He argues that the simplistic suggestion to enhance the production rate of the conventional building materials by unlimited exploitation of naturally available raw materials may lead to ecological disaster. According to him, India in 1980 required 70 billion bricks in urban area only. He assumes 1.2 metres of top soil for production of good quality burnt bricks and estimates that India will continue to lose 35,600 acres of fertile top soil annually. Similar examples regarding timber, cement, lime, etc., would establish the most urgent need to substitute the conventional building materials with a new range of materials that would be eco-friendly. Deb (1994) also states that all burnt clay products in India use coal, wood, lignite, etc., which deplete the energy resources and pollute the environment.

Natural and man-modified resources in developing countries exhibit extensive interdependence (Pearse and Turner, 1990). As demand for fuel wood increases, tree cover is reduced. According to Pearse and Turner, the renewable resources in the developing countries are being 'mined' in much the same way as exhaustible resources, which is a matter of great concern. Therefore, in Indian context, the rate of depletion of renewable sources of energy should be reduced.

As mentioned before, Maithel and Uma (2000) estimated that more than 100,000 kilns produce about 80 to100 billion bricks per year in India. According to them, coal is the major fuel used for firing bricks. It is estimated that the brick industry consumes about 15 million tons of coal annually. Mailthel and Uma state that, some technological improvements have been made in a section of the brick industry (mainly in large brick making units) after the Government of India set emissions standards for brick kilns in 1996. In addition to reductions in emissions, the regulations have resulted in some fuel savings. However, Mailthel and Uma do not provide any quantitative evidence in support of their statements.

According to Sjostrom and Bakens (1999), the construction industry and the built environment are the main consumers of energy and material resources. Within the European Union, buildings are estimated to consume approximately 40% of total energy, responsible for some 30% of CO_2 emissions and generate approximately 40% of all man-made waste. Cole and Rousseau (1992) state that though research in the mid 1970s clearly demonstrated that significant amounts of energies are required to produce a building; energy accounting over the past fifteen years has focused almost exclusively on operational energy use in buildings and the development strategies to reduce it. In the 1990s it became increasingly important to resume the work on evaluating the energy for producing buildings and to extend it to embrace a broader environmental agenda. Mithraratne and Vale (2003) state that although historically attention was focused on the operating energy, the importance of both embodied and operating energy attributable to buildings has been highlighted by recent Australian research. This dissertation is focused on rural school buildings in India. It may be noted that most of these schools do not have access to electricity (Das et al, 2004). It is, therefore, reasonable to consider only the issues of embodied energy and emission of CO_2 in the present context.

EMBODIED ENERGY

Each material used in construction has embodied energy, which is an important environmental parameter in this dissertation. It may be noted that the calculation of embodied energy of materials is a complex issue. According to Woolley et al (1999: 7), "*calculations of embodied energy are complex, for they include the energy from the extraction of raw materials through to processing and erection. Taking transportation (as well as infrastructure) into account, not to mention a portion of the energy used to make mining, processing, transportation and construction equipment, one has a challenging task to arrive at a comprehensive single figure for the embodied energy of any given material. Considering the variety of materials which go into any building, a single figure for a building is even more daunting.*"

The main problem is where to draw the boundaries and to highlight this, Woolley quotes from the Masters Thesis of Thomas Keogh (1996) at Queens University and asks "*should we consider the energy used to cook the building workers ['] breakfasts?*" This is a topic of concern to the researchers and professionals but as yet there is no internationally agreed method for calculating embodied energy. Following is a brief description on some of the methods of calculating embodied energy.

Method of calculating embodied energy: Since this dissertation is not focused on embodied energy analysis, a brief description on the different methods used in this context has been provided this section. According to Shipworth (2002), embodied energy analysis is dominated by two commonly used methods - process analysis and input-output analysis. Process analysis offers comparative precision and high product-process specificity, but lacks generality and suffers from incompleteness. Input-output analysis is comparatively better in terms of generality and offers completeness, but contains substantially greater uncertainties and lacks product specificity. The complementary characteristics of these two approaches have lead to the development of new hybridised models that selectively integrate process analysis data into an input-output framework on a prioritized basis (Treloar, 1997).

Fay et al (2000) refer to Boustead and Hancock (1979) to state that, in theory, process analysis is the simplest method of embodied energy calculation. This method focuses on energy required for particular industrial processes. In brick making, for example, the energy metered at the factory boundary can be measured (i.e., the direct energy requirement). However, such a measurement is incomplete because it excludes, for example, the energy used to extract clay from the ground and then transport it to the brick fields (i.e., indirect energy). Process analysis can be used to measure the energy used, e.g., per brick, for many of these processes. However, at each stage there may be many large or small inputs of goods and services which cannot be covered in detail using the process analysis method.

According to Fay et al (2000), the method that can provide an estimate of all energy embodied in a product is known as input-output analysis. This method makes use of national statistical information compiled by Governments for the purpose of analysing national economic flows between sectors. These economic flows can be translated into energy flows using average energy tariffs. Fay refers to Treloar (1997) to state that, while theoretically complete, this method has several methodological problems. Consequently this method is not considered reliable for embodied energy analysis of an individual product. Like Shipworth (2002) , Fay et al (2000) and Treloar et al (2000) also opine that hybrid analysis combines the strengths of process analysis and input-output analysis. According to Fay et al (2000), the most important deficiency with the hybrid analysis method is the lack of comprehensive and reliable database of energy use from industry.

Cole and Rousseau (1992) state that limited international research over the past 15 years in the field of energy intensities of building materials has reduced differences in the calculated values for some materials. Still, there are some significant differences in this regard for the following reasons;

System boundaries
Data source reliability
International differences
Thermal energy content of feedstock materials

System boundaries: Cole and Rousseau (1992) refer to Kohler (1991) and state that there is no absolute or correct energy intensity of a material. A stated value is a direct function of what was included and what was excluded from its derivation. Assessment of energy intensity figures must, therefore, be accompanied by definitions and clear boundaries. The commonly accepted limit includes analysis of all the industrial process of extraction, transportation and processing of a material, which typically captures about 90% of the gross energy requirements of a manufactured item. However, there may be important exceptions to this.

Data sources and reliability: the data sources for energy intensity analysis are also problematic since the three main sources of data; viz., National statistics, Process analyses and industry statistics are not necessarily available and may not produce reliable results. However, by using several types of analysis, one can judge the reliability of results through comparing the consistency of figures derived from different data sources.

International differences: there are several factors which also affect international figures and to some extent, even national figures. The most regionally available and inexpensive fuel is likely to be used, within regulatory boundaries. Some industries rely on imported raw materials for which the overseas extraction cost and energy may be difficult to assess. Different accounting methods could also make a difference at international level. For example in New Zealand, many non-ferrous metal statistics are lumped together making it difficult to distinguish copper from aluminium, etc. (Cole and Rousseau, 1992)

Thermal energy content of feedstocks: there are two ways of calculating energy content of the materials which are petroleum based. Some use their theoretical thermal value and other their actual value when burned in a process of average efficiency. Many researchers opt for the theoretical value and this explains the relatively high energy intensity for most synthetic resins.

According to Shipworth (2002), the current means of assessing the environmental impact of construction projects such as the Green Building Challenge's 'Green Building Tool's (discussed later), the US Green Building Council's Leadership in Energy and Environmental Design (LEED Rating System, 2001) and the Building Research Establishment's 'BREEAM' package and its variants, all have difficulty in assessing the first of these components – the embodied energy of construction. In the recent international trial of the newly developed 'second generation' green building assessment package the 'Green Building Tool', participants repeatedly reported difficulty in finding reliable data on which to base their assessment of the embodied energy of construction. Shipworth (2002) refers to Crawley and Aho (1999) and states that, while assessing the 34 buildings for the Green Building Challenge '98, it was found that determining embodied energy was extremely difficult and costly. Several countries decided specifically not to address it in their assessment.

All the problems mentioned in this section also exist in India. It is important to note that the Ministry of Urban Affairs and Employment, Government of India, had published a document that contained data on embodied energy of construction materials (Gupta, 1998). However, such data is far from satisfactory since the document does not explain the process of energy calculations. Their earlier publication "Home and the Family (Gupta, 1994) also provided data on embodied energy of some building materials such as cement, steel, etc., without explaining how they were derived. The researchers of the Tata Energy Research Institute, New Delhi and the Ministry of Environment and Forest, showed keen interest in the subject and provided important information on how to calculate CO_2, etc., which has been discussed in chapter 8 on data analysis.

Out of all these documents, the data provided by the Development Alternatives (Energy Directory of Building Materials, 1995), a Non Governmental Organisation in Delhi, is adopted here for the following reasons. Development Alternatives' study on embodied energy is based on – i) Energy for quarrying, including transportation to production site, ii) Energy for basic raw materials and processing, iii) Energy for production of materials including thermal, electrical but ignoring manual labour. The calculations have been based on common practices, the most accepted technology and best practice, which are usually characterized by adopting energy efficient measures without significantly changing the technology or type of fuel used. The Development Alternative's database is from different sources, e.g., while calculating transportation energy, it has adopted Tata Energy Research Institute's data (TEDDY, 1993). Development Alternative's database is not complete in every respect and some of them are outdated. For example, their data on cement has been updated with reference to the National Council for Cement and Building Materials (NCCBM, 2002-03), Government of India. All these have been explained in detail in chapter 8 on the database. Therefore, while the database on embodied energy adopted in this dissertation appears like hybrid process, it requires an in-depth research to come up with a single source of accurate handbook for the use of the architects, engineers and decision makers.

Let us now look at a different aspect of embodied energy. Thormark (2000) reports that, to reduce the negative environmental impacts owing to the building sector, recycling of building materials are on the increase. Projects are carried out on several levels and are often well analysed regarding the economic consequences; however, the actual environmental effects are rarely studied. Thormark (2000) presents a study of the environmental impacts owing to a building from 1997 with a large proportion of reused building materials and components. Two cases were studied; (i) the building as it was built with a large proportion of reused materials and components (ii) the building as if all materials and components had been new. The results showed that the environmental impacts were about 55% of the impacts that would have been caused if all materials had been new. The reuse of clay bricks and roofing clay tiles accounted for the main decrease in environmental impacts. Further, these materials can be transported over quite long distances and still give environmental benefits. However, progress in India in this respect appears to be slow, e.g., according to Gupta (1998), the slow implementation of research findings on the use of fly-ash by cement and concrete industries have been discouraging.

EMISSIONS

UNCHS(Habitat), (1991) report states that the pollution problem caused by building materials industries have attracted the attention of the environmentalists only recently. Energy efficient and pollution control technologies have, however, made few inroads in building materials industries in developing countries so far. Available technical innovations are either not accessible to these industries or their significance in reducing production costs and pollution is not well understood. According to the UNCHS (Habitat) (1991) report, the materials industries, of which building material production constitute a substantial part, account for nearly 20% of world fuel consumption. This along with the growing pollution problem will increasingly affect legislative action in developing countries. Hence, access to clean technologies, local building-materials industries, etc., would be of crucial importance in the near future. Raynsford (1999) reports that the energy use in buildings account for between 40% and 50% of the UK's emissions of CO_2.

According to the UNCHS(Habitat) (1991) report, many developing countries while acquiring new technologies for building materials industry, have often imported polluting technologies which have become obsolete in the western countries because of their strict pollution control legislation. Acquisition of such technologies is a retrograde step for the developing countries, as their eventual replacement by cleaner technologies would prove to be too costly and would put a brake on the industrialisation process of these countries. In this context Deb (1994)'s states that for ages, India has continued to use Bull's Trench Kiln, etc., for firing bricks, tiles etc., which has been discarded by many countries because of its high energy consumption and emission of CO_2.

It may be noted that the construction materials are produced by burning coal, oil/diesel, firewood and other types of biomass at high temperature, which generate CO_2. Most of the building materials emit pollutants because of coal burning. The construction sector in India is estimated to generate as much as 22% of CO_2 emissions since it consumes energy intensive materials such as iron, steel, cement, bricks, non-metallic minerals like glass, concrete, asbestos and wood (BMTPC, 1998). There are other sources of information regarding CO_2 emission in Indian construction sector. Tiwari et al (1996) calculated the sectoral CO_2 emission through an input-output approach for the Indian economy using 1983-84 data. The results showed that construction sector was the largest CO_2 emitting sector and its share was 17% of total carbon emissions. According to them, the main reason for this was the use of highly energy intensive materials like steel, cement, etc. According to Kumar et al (2000), the CO_2 emission in India has increased significantly. They reported that the construction sector is the largest contributor of CO_2 emissions in India and is responsible for 22% of the total, i.e., 5% increase between 1984 and 2000. Similar figures on CO_2 emission in the construction sector has been reported by Maithel (1999). Reducing the CO_2 emission by adopting appropriate materials and construction technologies may lead to indirect benefits to the Government of India which can do carbon trading with the developed countries.

Kumar et al (2000) opined that the major energy users in the building materials industry are the producers of cement, bricks, steel and lime. Maithel (1999) reports that the production of steel, cement and bricks, require burning of about 70 million tons of coal annually. He also reports that, the brick industry with an estimated coal consumption of 20 million tons per year is the third largest consumer of coal in the country after power plants and steel industry. Kumar estimates that cement, bricks, steel and lime together contribute 80 % of total CO_2 emissions from the Indian construction sector. The current demand for these four materials is expected to emit 81 million tons of CO_2. In the specific case of cement, per capita consumption is expected to increase from the existing level of 60 kilograms to 210 kilograms by the year 2020. The latter figure is equivalent to current consumption in developed countries. It is expected that, by the year 2020, their use will result in a threefold increase in energy requirements. The corresponding emissions will escalate to 285 million tons of CO_2. These projections are based on current technologies prevalent in the respective manufacturing sectors.

Parikh et al (1993) refer to Parikh and Gokarn (1993) and recommend that increasing construction efficiency by optimising the usage of less energy intensive material in construction technologies could be important in reducing CO_2 emissions. They have calculated that less bricks and cement-intensive construction techniques would reduce emission of CO_2 by about 21%, however, it would increase the building cost by 27%.

The United Nations Framework Convention on Climate Change was adopted in 1992. It provides the unifying framework of institutions and processes needed for global cooperation on climate change. This means that, whatever disagreements may have arisen over the Kyoto Protocol, the Convention's 187 Parties will continue to meet on a regular basis to discuss how to carry out their Convention-related commitments.

Under the convention, both developed and developing countries are committed to adopting national programmes for mitigating climate change. They are also to take climate change into account in their relevant social, economic, and environmental policies; cooperate in scientific, technical, and educational matters; minimize the effects of response measures on developing countries; and promote education, public awareness, and the exchange of information related to climate change. Additional commitments applying to developed countries only, include taking action aimed at stabilizing greenhouse gas emissions at 1990 levels by the year 2000 and providing financial and technological support to developing countries. The Convention sets out a number of guiding principles for global cooperation on climate change. The precautionary principle says that the lack of full scientific certainty should not be used as an excuse to postpone action when there is a threat of serious or irreversible damage. The principles of equity and of the common but differentiated responsibilities and respective capabilities of states confirm that developed countries should take the lead in combating climate change and its adverse effects. The principle of cost effectiveness seeks to ensure that the global benefits of minimizing climate change are achieved at the lowest possible cost. Other principles deal with the special needs of developing countries and the importance of promoting sustainable development. The situation in the developing countries is predicted to be alarming. The third assessment report of the Inter Governmental Panel on Climate Change (IPCC, 2001:12) states that; *"The impacts of climate change will fall disproportionately upon developing countries and the poor persons within all countries, and thereby exacerbate inequities in health status and access to adequate food, clean water, and other resources.*

Populations in developing countries are generally exposed to relatively high risks of adverse impacts from climate change. In addition, poverty and other factors create conditions of low adaptive capacity in most developing countries."

From the above discussion, it appears that CO_2 emission in Indian construction industry is a serious issue. To discourage the use of CO_2 intensive systems, there may be various strategies, e.g., Lowe (2000) suggests that regulation is overwhelmingly and obviously the best approach in certain areas of activities in this regard. The other approach could be carbon taxation, which means to raise the marginal price of energy in proportion to its carbon content. Lowe (2000) says that carbon taxation has a major advantage over traditional regulatory approaches. He opines that regulation and market based approaches appear to be complementary and mutually dependent. Lowe (2000) concludes that the evidence of anthropogenic climate change, though complex, is increasingly convincing. The energy and environmental performance of all buildings, particularly in the domestic sector, can in principle be reduced substantially through improved building regulations. Substantial progress towards the goal of reducing energy use and carbon emissions from buildings will require use of market mechanisms in support of regulatory approaches. The technologies to achieve large reductions in energy use in the main classes of construction exist, but there is presently little incentive for this.

The calculations of CO_2 emission in this dissertation has been based on the Development Alternatives' energy handbook (Energy Directory of Building Materials, 1995), which provides data on quantities and types of fuel required for materials such as brick, cement, steel, clay tile, etc. For those materials not covered by the energy handbook, calculations of CO_2 have been based on the carbon content and combustion efficiencies of petroleum, coal and firewood adopted from other sources described in chapter 8.

2.3.4 Life Cycle Analysis

It has long been recognized that evaluating the costs of buildings and engineering structures on the basis of their initial costs alone is unsatisfactory (Ashworth, 1993). While the effective consideration of the whole life costs is likely to result in large scale social infrastructure programme that offers the decision makers better value for money, there are problems which still need to be resolved before the method can be properly used in practice. These relate to the lack of knowledge and understanding on the part of both practitioners and clients and to a number of uncertainties, particularly with respect to historic data, the long term future time horizons and the policy issues of asset management.

The term "life cycle costing" originated in North America in the late 1950s (Ashworth & Hogg, 2000). Ashworth and Hogg referred to Hoar and Norman (1992) to state that, in the late 1970s, the US Government actively encouraged the use of life cycle costing. In the UK, it was referred to as costs-in-use. Ashworth and Hogg (2000) further state that, according to Flanagan and Norman (1983), the UK began referring to life cycle costing soon after the US. The strict definition of this term is the costs involved in purchasing and operating an asset. By definition, this includes initial construction costs and also the costs associated with its eventual disposal. There is evidence that the varying techniques used in different parts of the world for evaluating the costs of buildings and other structures are seeking out more common ground (Ashworth and Hogg 2000). This is especially true of life cycle costing where similar studies have revealed similar problems in application. In most of the cases, the overall approach is much the same. It consists, first, of examining different design proposals by assessing their respective costs, both initially as well as their life cycle. According to Ashworth and Hogg (2000), a frequently held reason for why the technique has not been widely used is the lack of appropriate, relevant and reliable historical cost information and data. Cole and Sterner (2000) emphasise that a life cycle cost analysis is a data intensive process and the final outcome is highly dependent on the accessibility, quality and accuracy of input data. However, even if the life cycle cost estimates for a whole building are preliminary and approximate, they can still expose significant cost areas and, therefore, provide an informed basis for subsequent planning.

Fay et al (2000) refers to Pears (1997) and states that the significance of Green House Gases attributable to building operation is well understood. Seo and Hwang (2001), in the context of Korea, examined the method for estimating CO_2 emissions given off over the entire life cycle of various types of residential buildings. For this, the life cycle of a residential building was divided into four stages – manufacturing of materials, construction, operation, and demolition. The result showed that CO_2 emissions resulting from construction, including manufacturing building materials for residential building, were in the range of 381.1 – 620.1 kilograms of Carbon per 10 square metres for each building type. However, most CO_2 emissions given off during the residential building life cycle were owing to the building operation having 87.5–96.9% of total CO_2 emissions. Therefore, in Korea, the emission of CO_2 up to the construction of residential building is not significant. This may be different in India and hence, there is a need to investigate this issue.

According to Mumma (1995), in a standard Canadian house in Toronto of 40-year life, the total embodied energy is 2352 Giga Joules. The total operating energy over 40 years is 9060 Giga Joules. Mumma does not mention about the area of the house in square metre. However, such data on CO_2 emission and embodied energy will vary from country to country owing to factors such as system boundaries, data source reliability, International differences and thermal energy content of feedstock materials.

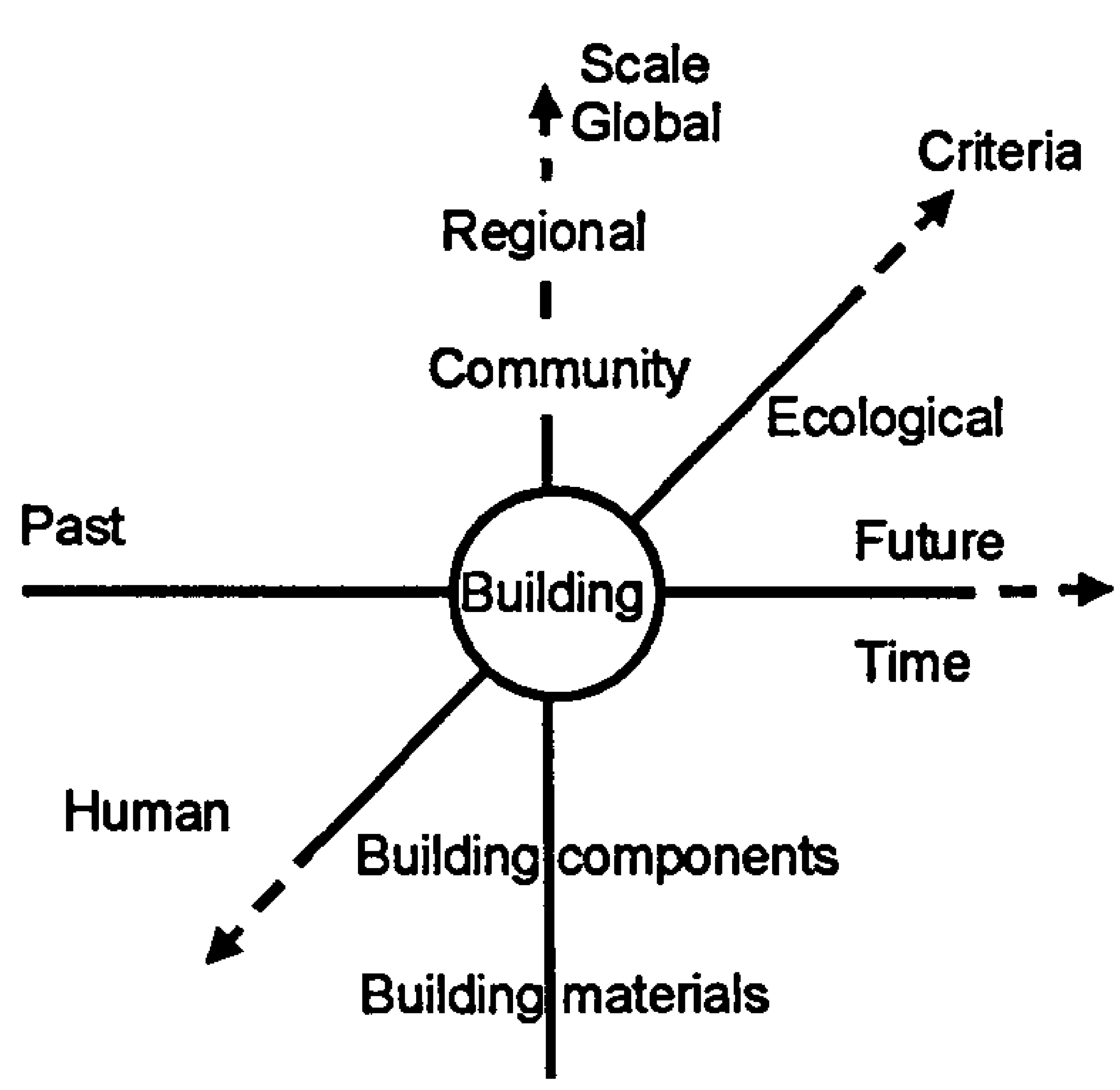
According to Shipworth (2002), life cycle environmental impact analysis of building is typically divided into three stages i) embodied impacts – impacts associated with the building's construction including those associated with the material inputs to the construction process, ii) operational impacts – impacts associated with the building's operation over its life and iii) disposal impacts – impacts associated with its demolition or decommissioning. According to the ATHENA Institute's (2000) report, natural resources, energy and water are required for a building starting from material acquisition, construction, occupancy, demolition down to the disposal of the debris. Similarly, emissions to air, impact on water and land should also be considered for life cycle environmental impact assessment. Therefore, life cycle environmental impact assessment method has to consider the way natural resources, energy and water emissions to air and land are affected owing to construction.

Let us now discuss the process of calculating life cycle impact of construction on the environment. Similar to Shipworth (2002), Fay et al (2000) also state that a building's life cycle energy consists of its initial embodied energy, its recurrent embodied energy and its operational energy over its lifetime. The energy embodied in a product comprises the energy to extract, transport and refine the raw materials and then to manufacture components and assemble the product.

A discussion on different methods of calculating embodied energy of construction materials has been carried out in the section on "Embodied Energy". Based on that discussion it has already been mentioned that the database of Development Alternatives (Energy Directory of Building Materials, 1995) is close to a Hybrid method and is perhaps the only complete source of embodied energy of basic construction materials such as cement, steel, brick, etc. Therefore, Development Alternatives' database will be adopted in this dissertation.

One of the crucial elements in life cycle impact assessment is its theoretical basis. Cole (1999) provides a complete picture of life cycle analysis of construction by defining the scope and boundaries of environmental assessment method. The Figure 2-1 shows a conceptual framework that can be used to illustrate the scope and boundaries of environmental issues in current building assessment methods. It consists of three primary dimensions, viz., Criteria, Time and Scale.

Figure 2-1 The domain of life cycle impact assessment, as suggested by Cole (1999)



Source: Cole (1999:239), Figure 3

Criteria: it consists of ecological concerns (resource use, ecological loadings, etc.) and human concerns (indoor environmental quality, economics, etc.). Each of these sets of issues can be further subdivided into - performance criteria that can be currently quantifiable and that can be confidently defined and assessed, such as energy use, water use, etc. These are shown as solid lines. Performance criteria that can currently only be described qualitatively such as loss of biodiversity, etc., are open to wider interpretation and therefore, their assessment is less certain. These are shown as broken lines. The criteria, such as, to what extent the reduction in CO_2 emission in building maintenance will affect the local climate is difficult to quantify and may be represented by dotted line.

Time: Adopting life cycle assessment approaches seem to be an appropriate basis for structuring performance criteria within building environmental assessment tools. However, Cole (1999) refers to Beetstra (1997) and states that, it may not be possible for all criteria. In Figure 2-1, both the distant past and long-term future are less clearly known and certain than the immediate past and future. As such, they are distinguished by periods of relative confidence (shown as a solid line) and speculation (shown as a broken line) respectively.

The certainty of predicting frequency of interventions depends to a large extent upon the historical database on the performances of the construction technologies over time. For example, the school buildings constructed under Andhra Pradesh Primary Education Project are due for another inspection in 2008, ten years after the first intervention. If such inspections are carried out till 2018, it will perhaps provide a dependable database for prediction.

Scale: Considerable strides have been made in the environmental performance and life cycle assessment of individual materials and components as well as their aggregation to whole building performance, the links between building and community and regional scale are less well developed.

One of the most important issues in life cycle assessment is the frequency of a particular type of maintenance requirement. In the context of life cycle energy analysis, Fay et al (2000) with reference to a two storey detached brick veneer house in Melbourne, Australia adopted the frequency of Painting as 10 years, window repairs/replacement as 50 years, plumbing and electrical systems repair between 25-75 years, appliances between 13-25 years and roofing materials between 25-50 years.

2.4 ASSESSMENT METHODS AND WEIGHTING

In the context of sustainable social infrastructure development, the above sections have carried out a detail discussion on the various issues relating to construction cost reduction, construction as an opportunity for poverty reduction and construction as a threat to the environment. These are identified from the last row "Issues in the construction sector" in Table 2.1, which is the summary (by the author) of different sources of definitions of sustainability. Such discussions will help in developing an assessment tool to indicate whether we are proceeding towards the goal of sustainability as suggested by Dahl (1995). To understand the context of developing an assessment tool, the discussion on sustainability has been summarized in Table 2.2.

Table 2.2 The domain of impact assessment tools based on the discussion on sustainability.

Sources	**Guidelines for impact assessment tools for sustainable development**
Viederman (1995)	the humility principle, which recognises the limitations of human knowledge, the precautionary principle, which advocates caution when in doubt, The reversibility principle, which requires us not to make any irreversible changes.
Plessis (1999)	sustainable development was also seen to imply certain qualitative issues surrounding human aspirations, emotional well-being and social relationships.
Cole (1999)	the notion of 'sustainability' is perhaps only meaningful when applied at a global scale.
Raynsford (1999)	protection of the environment both from global threats and at local level.
Dahl (1995)	danger of using indicators to make value judgements about the content of development, dynamic process like the sustainability of development is expected to have a moving target, sustainability can be represented by a vector indicating direction and speed of approaching the target.
Fricker (2001)	we have a better understanding of what is unsustainable rather than what is sustainable, un-sustainability is commonly seen as environmental degradation.
Lacasse (1998)	current trend of building design, engineering methods, manufacturing technologies and construction techniques need to be altered to accommodate requirements for sustainable construction.

Table 2.2 continued

Sources	Guidelines for impact assessment tools for sustainable development
Cole (1999)	sustainability must give direction to the structure and application of environmental assessment methods
AGENDA 21	environmental impact assessment, as a national instrument, -action to be taken globally, nationally and locally, all States shall cooperate in the essential task of eradicating poverty as an indispensable requirement for sustainable development, States shall facilitate and encourage public awareness and participation in dealing with the environmental issues.
The Millennium Development Goals (2003)	sustainable development to be integrated into country policies and program, reverse the loss of environmental resources.
Department For International Development (1999)	environmental sustainability is achieved when the productivity of life-supporting natural resources is conserved or enhanced for use by future generations.
Perrings (1994),	sustainable development is divisible - sustainability of the component parts could be devised in different sectors, resource categories and levels of society, incentives are important, the importance of maintaining the resilience of ecological and economic systems at appropriate levels, e.g., think of the behaviour at community level rather than of individuals, Refugees, victim of famines, disabled, children or the old will not behave sustainably.

Based on the above table, the following points will define the domain of the impact assessment tool.

- Considering the caution against the qualitative aspects of sustainable development, this dissertation will consider only the quantitative aspects at this stage of development in India. Later on, if the assessment tool is widely used and thereafter evaluated, the qualitative aspects could be included.

- Use of materials with low cost, low embodied energy and low emission of CO_2 is the first step towards sustainable construction. Use of local materials is the next step leading to low cost and higher income generation compared to that of the conventional construction system. The third step is the use of construction technologies that reduce unit cost, increase employment opportunities and minimises energy depletion and emission of CO_2.

- Sustainability considered in this dissertation is primarily at local level since the Andhra Pradesh Primary Education Project database, which will be used for impact assessment, is grass-root level information. The issues, such as, poverty and cost reduction in this context are local (district level). However, a separate research could be carried out to study its impact at the state, national and global levels. The depletion of non-renewable and renewable energy and emission of CO_2 are essentially global.

- Since sustainable development is divisible, the socio-economic and environmental parameters in the social infrastructure construction sector have been considered for impact assessment.

- Table 2.2 indicates that, sustainability has a moving target. This dissertation adopts the basic minimum services as the moving target, which is India's commitment to the international goals and targets and also an urgent requirement of its poor people. The requirements of the basic minimum services such as primary healthcare, primary school and housing are revised in every five year plan of India. The requirements of basic minimum services have been calculated according to the Tenth Five Year Plan (2002-2007), Census of India (2001), Housing Condition in India, (2004), etc.

- By adopting the recommendations of Agenda 21 and Millennium Development Goals, this dissertation attempts to develop an impact assessment tool, which could be used at national, state and district level. However, this dissertation does not attempt to show directly how the target of basic minimum services is going to be achieved. It will develop an impact assessment tool to guide the decision makers involved in social infrastructure development. This tool will enable them to optimise the socio-economic and environmental impacts by choosing the most sustainable construction technologies in the context of primarily the local issues and priorities. From the administrative point, the local level here means a district. At national level the tool will enable the decision makers to guide the local level decision makers if they are in clash with national and global objectives.

Having defined the domain of an assessment tool for sustainable social infrastructure in India, it is necessary to explore the existing literature on assessment methods. While browsing internet, reading books and journals in search of assessment methods in sustainable construction, one will frequently encounter the term "Green Building Tool". We shall, therefore, discuss "Green Building Tool" first.

GREEN BUILDING TOOLS

Kohler (1999) refers to Cole and Larsson (1998) and states that Green Building Challenge is a unique international project, which was initiated in 1995 by a group of researchers from the University of British Columbia along with Natural Resources, Canada. Under the general term of 'green building', a whole new way of building performance assessment was proposed. The first objective of Green Building Challenge was to overcome the shortcomings of existing environmental assessment tools. Cole (1999) reports that Green Building Tool as an assessment method was built on the limitations of existing methods and confronted areas of building performance assessment, which were previously either ignored or poorly defined. Under the name of second generation tools, they encompass mainly ranking and labeling tools, which had been pragmatically developed in the last few years and corresponded to an immediate need (Kohler, 1999).

According to Cole (1999), there are three distinct roles for building environmental assessment methods identified during the development and testing of Green Building Tool. The first among them was to provide a common and variable set of criteria and targets so that building owners striving for higher environmental standards will have a means of demonstrating that effort. The second was providing the basis for making informed design decisions, i.e., a design tool that can provide direction and guidance at all stages during the design development by highlighting priority issues and suggesting the possible trade-offs between options. The third was providing an objective assessment of a building's impact on the environment, i.e., a tool to evaluate energy and mass flows between built and natural systems and provide a common yardstick for measuring progress towards sustainability.

Kohler (1999) explains that the Green Building Challenge method is based on the 'distance to reference' principle, where the reference is an average building. The advantage of this method is the possibility to aggregate different criteria on the basis of their relative distance to the reference or target values. Green building practice, as Cole (1999) explains, assumes that by continually improving the environmental performance of individual buildings, the collective reduction in resource use and ecological loadings by the building industry will be sufficient to fully address the environmental agenda. However, according to Kohler (1999), Green Building Challenge has raised many questions about green buildings and the way to realize them. The attempt to bring together different aspects has raised the problem of their relative importance. One criticism of Green Building Challenge is that there is no objective scientific weighting of the different aspects of sustainability. Kohler states that weighting can only result from a social process of discussion about the future that we want. In this regard, Todd and Geissler (1999) opine that we should set our system boundary of weighting of importance at the 'world' level.

According to Cole and Mitchell (1999), the Green Building Challenge process showed that, users need time to become familiar with an assessment procedure. At a practical level, issues of terminology and language become important in the implementation of a general assessment method. A suggestion from several teams was that it is possibly better to start slowly and with a less comprehensive approach, but with a set of core criteria which can be extended as experience develops. It is evident that a much clearer and consistent set of directives must be provided to assist in any customization process than currently evident within the Green Building Challenge process. Let us now look at some other assessment methods.

The EcoBalance model was developed in Finland in early 1990s (Harmaajärvi, 2000). This model is divided into three sub-models: production, operation and transportation. The ecological balance sheet has dimensions, viz., consumption of energy, consumption of natural resources (fuels, building materials, water), emissions, wastes and costs. Harmaajärvi (2000) states that, with the help of EcoBalance model a study was conducted in four existing Finnish eco-villages, which were being developed with environmental interests as a priority. The study also compared with two conventional Finnish areas of detached houses. It was revealed that in a 50 year period, the villages require 800-1200 Mega Watt-hours energy per inhabitant and 17.4 – 33.2 Mega Watt-hours per square metre. Energy consumed in Puutosmäki is more than in other areas because of high heating energy, long distances and wide use of private cars. The least energy is consumed in Ekolehtlä, which is located close to the city centre, and light traffic is thus widely used. The study areas require 190-420 tons of raw materials per inhabitant and 5.3 – 11.3 tons per square metre in a 50 year period. Of these, on average, 60% comprise building materials and 40% fuel. CO_2 accounts for 160-240 tons of emission per inhabitant and 3.8-6 tons per square metre of floor area in 50 year period. The majority of CO_2 emission is caused by heating and electricity consumption of buildings. Such valuable data on the life cycle impact on environment will enable decision makers to make sustainable future interventions.

According to Holm (1998),"Building Research Establishment Environmental Assessment System (BREEAM)" is the first and most widely known among the assessment methods for environmental sustainability of buildings and building products. Dickie and Howard (2000) state that BREEAM is also intended to be used at design phase. It considers issues like energy for operational use and CO_2 emission, materials, transport, etc. (EcoHomes, 2003). However, according to them, many countries are using BREEAM as a reference document rather than adopting it whole, reflecting the fact that the system was not originally designed to accommodate national or regional variations. Cooper (1999) also criticizes BREEAM. He reports that several groups reviewed BREEAM by using four principles as an analytical frame: Futurity – concern for future generation, Environment – concern to protect the integrity of eco-systems, Equity – concern for today's poor and disadvantaged, Public Participation – concern that individuals can participate in decisions affecting them. This method of reviewing revealed that BREEAM was seen as predominantly concerned with 'environment', with minimal attention to 'futurity' and 'equity', and none to 'participation'. Cooper states that if this judgement is valid, then BREEAM, Green Building Challenge '98 and other existing methods for assessing buildings - whose remit is largely restricted to an environmental protection and resource efficiency agenda - have limited utility for assessing 'socio-economic' as opposed to 'environmental' sustainability.

However, BREEAM is one of the first few methods of environmental impact assessment and has influences on some of the later developments in this field. Holm (1998), states that a well-known first generation system is the Canadian method "Building Environmental Performance Assessment Criteria" (BEPAC). The developers had the advantage of having BREEAM as a prior model. The result is that BEPAC is more detailed and comprehensive in comparison with the first BREEAM variants. BEPAC is limited to office buildings.

Gerard et al (2000) describes ESCALE, which is a method for assessing the environmental quality of buildings at the design stage. The method considers two types of evaluation criteria: purely environmental criteria (8 technical criteria and 1 organizational criterion), and indirectly environmental criteria, i.e., specific concerns of certain parties whose results and actions may have an indirect impact on environmental performances. The direct and indirect environmental criteria are energy resources, other resources, waste, large scale pollution, local pollution, contextual fit, comfort, health, environmental management, maintenance and adaptability. Based on the eleven main criteria, an entire sub-criteria has been developed, thereby generating detailed sub-criteria up to the level of elementary criteria. This is a detailed approach and at this moment India does not appear to be anywhere close to this.

Holm (1998) states that the US Green Building Council (USGBC), has launched a system designed specifically for use as a green labeling system for rating the performance of commercial office buildings. The system, known as "Leadership in Energy and Environmental Design" (LEED). "THE VERSION 2.0" of LEED (LEED, 2001) is a check-list type rating system, which uses a simplified format that facilitates its use in the design process. The criteria in the system are linked to a series of existing performance standards.

The GRIP centre, funded by the Norwegian Ministry of Environment, has developed a system called the "Eco-Profile" for buildings (Holm, 1998). The first version of the assessment method is developed for commercial buildings. A version for homes is under development at the present time. The "Eco-Profile" for buildings gave impulses to initiating a common environmental assessment cooperation project for the Nordic countries, viz., Norway, Sweden, Finland, Denmark and Iceland. Similar development projects are also going on in the Netherlands, Hong Kong and other countries.

Lippiat and Boyles (2001) describe a tool for selecting cost effective green building products called the Building for Environmental and Economic Sustainability (BEES). According to them, the technique is based on consensus standards and designed to be practical, flexible, and transparent. Version 2.0 of the Windows-based decision support software, aimed at designers, builders, and product manufacturers, and includes actual environmental and economic performance data for 65 building products across a range of functional applications. BEES measures the environmental performance of building products using the environmental life cycle assessment approach specified in the International Standards Organization (ISO) 14040 series of standards.

Applying the BEES approach leads to several general conclusions. First, environmental claims based on single attributes, e.g., recycling or reduced global warming alone, should be viewed with skepticism. These claims do not account for the fact that other impacts may indeed cause equal or greater damage. Second, assessments must always be quantified on a functional unit basis, such that the products being compared are true substitutes for one another. For example, one roof covering product may be environmentally superior to another on a kilogram-for-kilogram basis, but if that product requires twice the mass as the other to cover one square meter of roof, the results may reverse. Third, a product may contain a high-impact constituent, but if that constituent is a small portion of an otherwise benign product, its significance decreases dramatically. Finally, a short-lived, low first-cost product is often not the cost effective alternative. In sum, the answers lie in the trade-offs.

It is evident from the above discussion that most of the tools consider environmental impact assessment only. Therefore, there is a need for developing a tool combining the three pillars of sustainability. Tiwari et al (1996) have developed a mathematical model for evaluating various alternative construction technologies. They have assumed one room of dimensions 3.5metres x 3.5metres x 4.14metres constructed with one brick thickness wall. Their model includes low cost techniques, in which, the unit cost, labour intensity and CO_2 emission are calculated at three stages. The first stage is called "Primary Inputs", whose outputs are cement, brick, steel, aggregate, etc. The second stage is called "Intermediate Inputs", with outputs, such as, pre-cast hollow concrete blocks, stabilised mud blocks, etc. The third, i.e., "Final Inputs" lead to building construction as a complete product.

Tiwari et al's (1996) model assumes that low cost materials are essentially low CO_2 emission intensive. The objective function set by them is to minimise the cost of construction and labour cost and it does not include the issue of CO_2 emission. Tiwari treats the effect of CO_2 emission separately. The unit costs used in the model have been compiled from Delhi Schedule of Rates (1989) and books on estimation. The cost of low cost materials are compiled from various sources (not mentioned in the paper) and through personal discussions, which appears to be the weak point of the results of the exercise. The database used in the model is for new construction only. While this model has considered socio-economic and emission of CO_2 in construction, it has several areas that needs further development. For example it needs to consider the embodied energies of different types, i.e., non-renewable, renewable and waste, in the entire process of building construction.

It is important to note that Cole and Mitchell (1999), in reviewing the Green Building Tool output profiles, observed that there is no consensus on what constitutes a "Green Building". Existing assessment systems and the Green Building Tool system are helping to lead to an acceptable definition, but this will take time. In addition, Cole and Rousseau (1992) reports that, while environmental studies have produced considerable data on the environmental effects of the processes and materials associated with building construction, very little is available in a form, suitable for the design professionals. According to Kohler and Lützkendorf (2002), designers, owners and developers of buildings have been demanding simplified ratings of building performance to identify 'green' buildings on the market. A number of available assessment tools (BRE, 1993) have delivered this function well for several years. They are, however, not well suited for the use of comprehensive planning teams during the various design phases. Crawley and Aho (1999), suggest that the central issue in mitigating environmental impact is the need for a practical and meaningful yardstick for measuring environmental performance, both in terms of identifying starting points and monitoring progress.

In the context of environmental impact assessment, Steen (2001) thinks that a basic question "how do we define the environment and how do we see if it improves or degrades?" must be answered before any impact assessment can be made. Our conceptual understanding of 'the environment' and its values can be described through answering three questions. The first one is - what is included in our care for the environment? The second one is - How do we make trade-off between different impacts? The third one is - How do we handle uncertainty?

Lessons Learnt

It may be reiterated that the above discussions show that the assessment methods are mostly on environmental sustainability, which may not be suitable in developing countries like India with financial constraint and poverty indicated in the Tenth Five Year Plan (2002-2007). Todd and Geissler (1999) suggest that a regionally adaptable system that assesses the "green-ness" of buildings while taking into account of the social and economic issues, begins to address the sustainability of buildings. Tiwari et al's (1996) model does consider the socio-economic aspects, however, its environmental consideration is inadequate. As mentioned above, they did not consider the embodied energy. However, their model is perhaps one of the few which attempted sustainable social infrastructure development by considering some aspects of the socio-economy and environment. UNCHS (Habitat) (1991) report states that, unfortunately few developing countries have acquired the expertise or infrastructure to evaluate technological options, more so in basic building materials industries where traditional technologies still maintain a firm hold. Until recently, diffusion of new technologies has been mostly limited to cement and brick industries.

This dissertation will attempt to develop an impact assessment tool based on the lessons learnt from the Green Building Challenge. It will also accept the Green building practice's assumption that, by continually improving the environmental performance of individual buildings, the collective reduction in resource use and ecological loadings by the building industry will be sufficient to fully address the environmental agenda. While evaluating the alternative construction systems, the impact assessment tool will attempt to combine the effects of the socio-economic and environmental aspects to arrive at trade-offs, as suggested by Lippiat and Boyles (2001). The assessment tool in this dissertation is based on Todd and Geissler's (1999) suggestion of considering the social and economic issues along with greenness of buildings. Tiwari et al's model will be used as a reference. Last but the most important suggestion adopted in the impact assessment tool is that, we should start slowly and with a less comprehensive approach, but with a set of core criteria which can be extended as experience develops.

The scale of impact has been assumed to be mostly at district level. It has been mentioned before that, according to Raynsford (1999), the issues like poverty, embodied energy and CO_2 emission are both global and local. Theaker and Cole (2001) state that the initiatives and lessons demonstrated by local Government can affect the policies and programmes of larger Governments (a 'bottom-up' approach). Sustainability is local – the day-to-day experience of local Government gives a more intimate experience of local conditions. Politics is local – public concern and activism is more effective at the local scale. City and regional politics are more accountable, since politicians are closer to their electorate, accessible to citizens face-to-face, directly affected by citizen activism, and have a smaller remit than politicians in larger arenas. This dissertation shall, therefore, deal with sustainable social infrastructure development primarily from a local point of view (district level).

WEIGHTING

According to Todd et al (2001), all the assessment systems use some form of weighting, even if it is 'no weighting', i.e. all weights are same. Weighting systems are fraught with difficulty since they cannot be accomplished with complete, or in some cases, any scientific objectivity (Todd et al 2001). Cole (1999) states that, within the Green Building Challenge documentation a series of criteria were offered as a basis for developing appropriate weightings. For example, is the effect upon the environment irreversible? Is the effect upon the environment long lasting? What numbers of people are affected by the issue covered within the sub criterion or criterion? Does the practice in question have momentum that will require an extraordinary effort to counter? While these four points show positive direction towards weighting calculation, Cole (1999) criticizes by saying that no clearly defined methodology has been proposed for their application. One criticism was that these recommendations mix the importance of a criterion or sub-criterion in terms of its effect on human health, wellbeing, or the environment, with the difficulty of achieving it.

Cole and Mitchell (1999) state that Green Building Tool provides a performance scale for each assessed sub-criteria and criteria, using a consistent metric of - 2, to +5, with 0 representing typical practice for the building type in the particular region. A series of default requirements are provided to indicate the necessary performance needed to attain a given score. These default values and associated texts were a means of denoting the intention of the sub-criteria/criteria and it was anticipated that the decision makers would interpret them and, if necessary, change the default performance scale to reflect national and regional concerns and priorities. Cole and Mitchell (1999), state that a set of default weightings is incorporated in Green Building Tool to derive summary scores at the criteria, category or overall building level. For the main part, these default weightings are given equal value for all sub-criteria within a given criterion, and for all criteria sets constituting a given category. Exceptions to this general rule were made to reflect acknowledged issues such as the importance of annual operating energy compared to other life cycle stages, reuse of existing buildings, etc., each of which were given higher weightings within their respective sets.

One of the widely used methods of weighting calculation is Analytical Hierarchical Process, which has been described as a comprehensive, logical and having structural framework in a report by "isnar" (no date). The prioritisation process is accompanied by assigning a number from a scale developed by Saaty (Nataraj, 2005) to represent the importance of the criteria as shown in the following table.

Table 2.3: Saaty's scale of importance of the criteria.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Slightly favours one over another
5	Essential or strong importance	Strongly favours one over another
7	Demonstrated importance	Dominance of the demonstrated
9	Extreme importance	Evidence favouring one over another of the highest possible order of affirmation.
2,4,6,8	Intermediate values	When a compromise is needed.

Source: Nataraj (2005:3)

If a decision maker believes that safety is far more important than aesthetics with respect to the goal, a weighting of 9 to safety expresses this judgement. Nataraj (2005) refers to Partovi (1994) and states that the Analytical Hierarchical Process, developed by Thomas Saaty can be used in making decisions that are complex, unstructured and contain multiple attributes.

Kogelheide (2004) demonstrates the actor collaboration to prioritise objectives in the development of a "Sustainability Assessment Tool" for the context of Brownfield Regeneration. He shows that participatory workshop is a key element of "Sustainability Assessment Tool", in which the actors assign weights on sustainability objectives to express their priorities by justifying, arguing, negotiating, understanding and learning. In that context, out of 34 objectives of the programme, 11 were weighted by the participatory process and the remaining 23 objectives are not weighted, e.g. compliance with European Union-standards on groundwater quality, emission controls, health and safety. Relevant actors were the site owner, investor, developer, local authorities, (regional / national authorities), quarter inhabitants, neighbourhood, associations, Non-Governmental Organisations, community based organisations and media representatives.

One of the objectives of the Brownfield Regeneration Programme was to generate and safeguard employment and economic development. Based on the information of the regional employment situation, the participants were asked – "which kind(s) of jobs should be created by the project?" the weighting question was – "Allocate your points to the following categories with regard to their importance". This process appears to be a good model of beneficiary-participated weighting method and can influence project development from early stage by facilitating face-to-face communication between local authorities, planners and citizens. The process adopted in Brownfield regeneration was transparent, participatory and simple.

Out of the methods of weighting discussed in this section, Saaty's method and Brownfield Regeneration experience appears to be simple and participatory by involving the end users.

Analytical hierarchical process is a convenient method; however, the results depend upon the way inquirer explains the method and also the level of understanding of the people taking part in it. One has to trial run Saaty's method in the current domain of research by involving several groups of people to make the results reliable. Therefore, it appears that proper justice in this regard cannot be done in this dissertation.

The Brownfield Regeneration experience suggests that the process of prioritising the objectives in sustainability assessment tool can be understood by the stakeholders. However, Steen (2001) refers to Fallenius et al (1997) and states that investigations show that ordinary consumers have a very limited ability of understanding complex environmental information. The field experience in Orissa and Andhra Pradesh, where community based healthcare and primary education infrastructure were constructed, reveal that Steen's observation is valid in rural India. While Brownfield Regeneration appears to have made the process suitable to the beneficiaries, at this point it appears that one needs further research in weighting. This dissertation is an attempt to develop an impact assessment tool and the issue of weighting is beyond its scope. This dissertation will carry out a limited study on how the weights affect the results of the impact assessment tools, which is shown in chapter 12.

2.5 PREMISE OF SUSTAINABLE CONSTRUCTION IN INDIA

The above discussion has identified the domain of sustainable social infrastructure in rural India, viz., lowering unit cost of construction, increasing construction-related employment opportunities, minimising embodied energy and emission of CO_2. Therefore, the next step is development of an impact assessment tool. It may be reasonable to assume that sustainable social infrastructure development in India should ideally be based on life cycle impact assessment of the construction technologies. However, it is equally important to show that assessment tool based on data of new construction is inadequate. Therefore, the tool should be able to demonstrate the impacts of new construction and also the life cycle implications for comparison. The impact assessment tool will be based on the following.

1. Use of cost effective construction technologies to reduce the unit cost of construction, which will enable us to build more floor space within the resources.
2. Use of labour-intensive technologies to help in reducing poverty.
3. Use of local materials to increase income-multiplier effect to approximately two.

4. Ensure that the materials and methods of construction do not recklessly deplete the natural resources by;
   adopting technologies that use materials of low embodied non-renewable and renewable energies.
   preferring renewable energy over the non-renewable.
   encouraging those technologies which are based on industrial and agricultural waste

5. Technologies that have the lowest CO_2 emissions.

6. Social infrastructure development programmes should be community centred.

7. The Government should assess impact of every project for sustainability.

Considering the seven points, an impact assessment tool will be developed in the context of India to enable the decision makers to make an informed choice about technologies for sustainable social infrastructure construction. The assessment tool in the context of social infrastructure development in India is very important since the construction requirements for its more than one billion population is high. Therefore, at this point it is necessary to have an idea on the magnitude of social infrastructure needs in India based on available data in this regard. The next chapter carries out this calculation.

CHAPTER 3 THE SOCIAL INFRASTRUCTURE NEEDS

3.1 THE CONTEXT

260 million people In India did not have incomes to access a consumption basket which defines the poverty line (Tenth Five Year Plan, 2002-2007). In India, this line is drawn at the level of income assumed to be necessary to provide individuals living in rural and urban areas, a daily calorie intake of 2,400 and 2,100, respectively, in addition to basic non-food items. Apart from that, households who do not have any of the following, is taken to be below poverty line: operating more than 2 hectares land, have pucca house, any member of family earning Rs.20,000 (£250) (or above) per annum, household owning any of the following: TV, refrigerator, ceiling fan , motorcycle / scooter, Three wheeler, Tractor, Power tiller, Combined thrasher/harvester (Frequently Asked Questions, no date).

Of the 260 million poor people in India, 75% are in the rural areas. The Tenth Five Year Plan (2002-07) reports that India is a home to 22% of the world's poor. It also states that such a high incidence of poverty is a matter of concern and hence, poverty eradication has been one of the major objectives of the development planning process. Apart from the low level of income of the people, their living conditions are poor and the existing infrastructure is also inadequate. Because of poverty, poor people cannot maintain their shelters neither they can afford to build a permanent house. The Government is also unable to provide basic minimum services such as primary education and primary healthcare infrastructure to all its citizens owing to fund constraints. Presently, the main focus of the ninth and tenth five year plan have been poverty alleviation and facilitating the poor people an access to shelter, primary education and primary healthcare facilities. Under such circumstances, there is a need for integrating the issues of poverty and the basic minimum services in the social infrastructure development programmes. While low unit cost of construction should be the first choice, the Government should also view infrastructure supply as an opportunity for employment generation. However, to carry that out, one should know the extent of infrastructure requirements in India.

Over the last few centuries, India's population has increased phenomenally and the majority lives in the rural areas. Table 3.1 shows the population statistics of a few selected countries. It may be noted that while China has the world's highest population, the population density in India is 2.34 times more than that of the former.

Table 3.1: Population of the three most populous countries.

Sl no	Country	Reference date	Population in million	Area in sq.km	Density of Population/ sq.km
1	China	2000	1,277.60	9,560,900	133.63
2	India	2001	1,.027.00	3,287,263	312.42
3	U.S.A	2000	281.40	9,809,386	28.69

Source: Census of India (2001), volume-1, P-29

As one would expect, the basic minimum services, i.e., shelter, primary healthcare building, primary school required for a vast country like India is huge. Maintenance of such facilities is also equally difficult owing to the scarcity of resources. The Government of India, through its various programmes, has been trying to provide the basic minumum services to all (Ninth Five Year Plan, 1997-2002).

Data on the shortfall of social infrastructure under basic minumum services is available in the Tenth Five Year Plan (2002-07), Census of India (2001), the National Building Organisation (NBO, 1996), the Building Materials and technology Promotion Council and Symbiosis of Technology, Environment and Management's data (BMTPC and STEM, 2000), Housing condition in India (2004) and Tenth Five Year Plan (2002-2007). Based on these sources of data, this section will focus on the shortfall of the primary education, primary health and education and housing to have an idea on the immediate financial requirement in this regard. While the title of the dissertation indicates that primary education is the focus; primary health and housing have also been included in this chapter for the purpose of estimating the cost of supplying basic minimum services. It may be noted that, while examining the different construction technologies under the Andhra Pradesh Primary Education Project, most of the options available were from the housing sector. As mentioned in chapter 2, the Orissa health project was a direct influence of Andhra Pradesh Primary Education Project. Therefore, while the dissertation will be based on the experience and database on primary schools, it will also benefit the primary healthcare and housing sectors. The following paragraphs will investigate the shortfall of all three categories under the basic minimum services.

One of the critical issues in such calculation is the data source. While, there are several sources, the emphasis in this dissertation has primarily been on the Government published database, e.g., Census of India (2001), the National Building Organisation (NBO, 1996), the Building Materials and technology Promotion Council and Symbiosis of Technology, Environment and Management's data (BMTPC and STEM, 2000), Housing condition in India (2004) and Tenth Five Year Plan (2002-2007). Year 2002 has been taken as the baseline since that is the starting point of the Tenth five year plan.

3.2 NEEDS IN THE PRIMARY EDUCATION SECTOR

The national norm for primary education is to supply a two classroom unit for settlements having at least 300 people and no school within 1 kilometre (Govinda, 2002). The national norm for the minimum area of a school campus is 1 acre. Apart from that, each school should have toilets and drinking water according to the national standards. There are many settlements in India where the number of classrooms in a primary school is at least five with a teachers' room. Therefore, the realistic calculation of a new school complex is quite huge. In general there is a shortage of funds for maintenance of the existing school buildings. The Government schools are owned by the Education Department and the responsibility for maintenance is delegated to the Works Department, Panchayati Raj Institutions, District Rural Development Agency, etc. The emphasis on the school maintenance is quite poor and, socio-politically, new construction is preferred owing to its visible impact to the common people.

Primary education had been a major priority area during the Ninth Five Year Plan (1997-2002). It was envisaged that there will be an additional enrolement of 25 million children at lower primary level and 16 million at upper primary level. 75,000 additional classrooms/ schools will be constructed at elementary level (Ninth Five Year Plan, 1997-2002). This is under the assumption that the existing schools would accommodate some of the additional learners. However, the Ninth Plan does not cite any reference in support of this assumption.

A conventional method that is frequently used in planning is to work with figures available from official educational records, viz., gross enrolment ratio and net enrolment ratios. This estimation differs widely as evident in Table 3.2.

Table 3.2: The estimate of out-of-school children in India from different sources.

	Description	Source	No. in million
1	6-14 years' out of school children	Census of India, 1991	75.4
2	6-14 years' out of school children	Saikia committee, 1997	63
3	Children engaged in full time work as child labourers	National Herald, 2 Jan. 1997	60
4	Child Labour working 12 hours a day on an average	CACL (The Campaign Against Child Labour)	70-80
5	Bonded child labourer (forced to work)	Bandhua Mukti Morcha	65

Source: Jain et al, (2002), Table 4.1, P-55

The discrepancies in the numbers of out of school children assume confusing proportions when the calculations are made on the basis of statistics of child labourers in India. Jain et al (2002) refer to Jagannathan (1999) and state that, despite 150 million children being enrolled in 800,000 schools that provide primary education (within a 1 kilometre) to the children in 95 % of the country, 350 million children remain out of school and an equal number do not complete even five years of schooling. To accommodate 350 million children one needs 8.75 million classrooms, which is a huge figure. Govinda (2002) estimated that the number of children not going to schools was 40 million in the year 2000. This would require 1 million additional classrooms to accommodate them based on the national standard of 40 children per classroom.

According to the Tenth Five Year Plan, out of approximately 200 million children in the age group 6-14 years, only 120 million are in the schools. Therefore, to facilitate primary education for the 80 million out-of-school children, there is a need for 2 million classrooms according to the national standard of 40 children per class. The carpet area of a classroom for 40 children, based on the national standard of 0.74 square metre per learner, is 29.6 square metre. Assuming a 230 mm thick brick wall, the covered area of a classroom is 35.52 square metre. The financial requirement for constructing 2 million such classrooms has been based on the construction cost of rural houses, which is Rs.2,837 (£35.5) per square metre (Housing Condition in India, 2002:51). It is a reasonable assumption since most of the schools under this category are in the rural areas and the specifications are similar. Based on the covered area of 35.52 square metre and unit cost of Rs.2,837 per square metre, the total financial requirements for clearing the primary education backlog in India is Rs.202 billion (£2.53 billion) to achieve the goal of providing access to all the children aged between 6-14 years. However, this calculation does not include the needs for additional rooms in overcrowded schools, schools run in rented premises and repair of dilapidated schools.

3.3 NEEDS IN THE RURAL PRIMARY HEALTH SECTOR

During the sixth five-year plan the national norm for a three tier rural primary healthcare infrastructure consisting of the Sub-Centre, Primary Health Centre and the Community Health Centre were evolved. While the sixth and seventh plan witnessed major expansion of the rural healthcare infrastructure, the Eight Plan concentrated on the efforts on development, consolidation and strengthening of the existing healthcare infrastructure to bring about improvement in quality and outreach the services. Ninth Five Year Plan (1997-2002) states that the national norm for a Sub-Centre vary between 3000-5000 population depending upon terrain and location; on similar considerations the norm for a Primary Health Centre is 20,000-30,000 and for every four Primary Health Centres there should be one Community Health Centre. In accordance with the national norms, the requirements for population of 1991 are 134,108 Sub-Centre, 22,349 Primary Health Centre and 5,587 Community Health Centre. According to Ninth Plan, the corresponding shortfall were 1378 Sub-Centres, 495 Primary Health Centres and 3163 Community Health Centres and the estimated expenditure was Rs.70 (£0.88) billion (Ninth Five-Year Plan, 1997-2002 :405).

According to the Tenth Plan, 8,181 Sub-Centres, 1,714 Primary Health Centre and 2,562 Community Health Centres were required (Table 3.3) in 2001. In this section, sub-centre and primary healthcare facilities only will be considered under basic minimum services since without them, people living in the physically isolated villages due to bad access roads, etc., are the most vulnerable ones.

Table 3.3 Shows the rural healthcare infrastructure in India.

	Sub centres		**Primary Health Centres**		**Community Health Centre**	
	Required 1991	Goal for the 10th Plan	Required 1991	Goal For the 10th Plan	Required 1991	Goal For the 10th Plan
Total	134,108	8,181	22349	1,714	5,587	2,562

Source: Tenth Five Year Plan (2002-2007 :147); Figures on shortfall are as on 31.3.2001; based on Health Information of India, ISM&H in India and D/O Family Welfare; figures are provisional

The unit rate for construction of healthcare facilities is higher than house construction since the former has superior specifications and needs facilities such as supply of hot water, lighting for the operating theatre, etc. However, there is a wide variation of unit costs of healthcare building construction across the country and no reliable national average is available in this regard. Therefore, the cost of house construction (rupees per square metre) in the urban areas has been used for calculating the financial requirements to supply the required number of sub-centres and primary health centres according to the Tenth Five Year Plan, which is shown in Table 3.4.

Table 3.4 The total financial requirements of the sub-centre and primary health centre backlog. Calculations based on the unit cost house construction in urban areas (Rs.80 = £1)

	Number of units	**Covered area/ unit (square metre)**	**Total covered area (square metre)**	**Unit cost (Rs. Per square metre)**	**Total amount (billion Rs.)**
Sub-centre	8181	70*	572,670	4853**	2.80
Primary health centre	1714	280*	479,920	4853**	2.33
Total amount of money required to clear the backlog					5.13

Source : * (Das, 1999:35), ** Housing Condition in India (2004), Statement 30, P- 51

The covered areas of the sub-centre and the primary health centre have been based on the DFID-funded Orissa health project (Das, 1999). These figures exclude repair of the existing helathcare facilities and also small isolated villages having population less than 3,000.

3.4 NEEDS IN THE HOUSING SECTOR

Shelter for the poor has been a high priority of the Government of India. A programme called Indira Awas Yojna was initiated in 1985-86 by the Central Government, which aimed to provide free housing to the Below Poverty Line families in the rural areas. It targeted the Schedule Caste/Schedule Tribe households and freed bonded labourers. An evaluation of the Indira Awas Yojana reveals that, the coverage of the beneficiaries has been limited owing to the resource constraints. The Government has been trying to provide shelters to its citizens. According to the Ninth (1997-2002) and Tenth Five Year plans (2002-07) Government of India has housing supply programmes such as credit-cum subsidy, Samagra Awas Yojna (Shelter for all), etc. Let us now examine the housing shortfall based on 2001 Census.

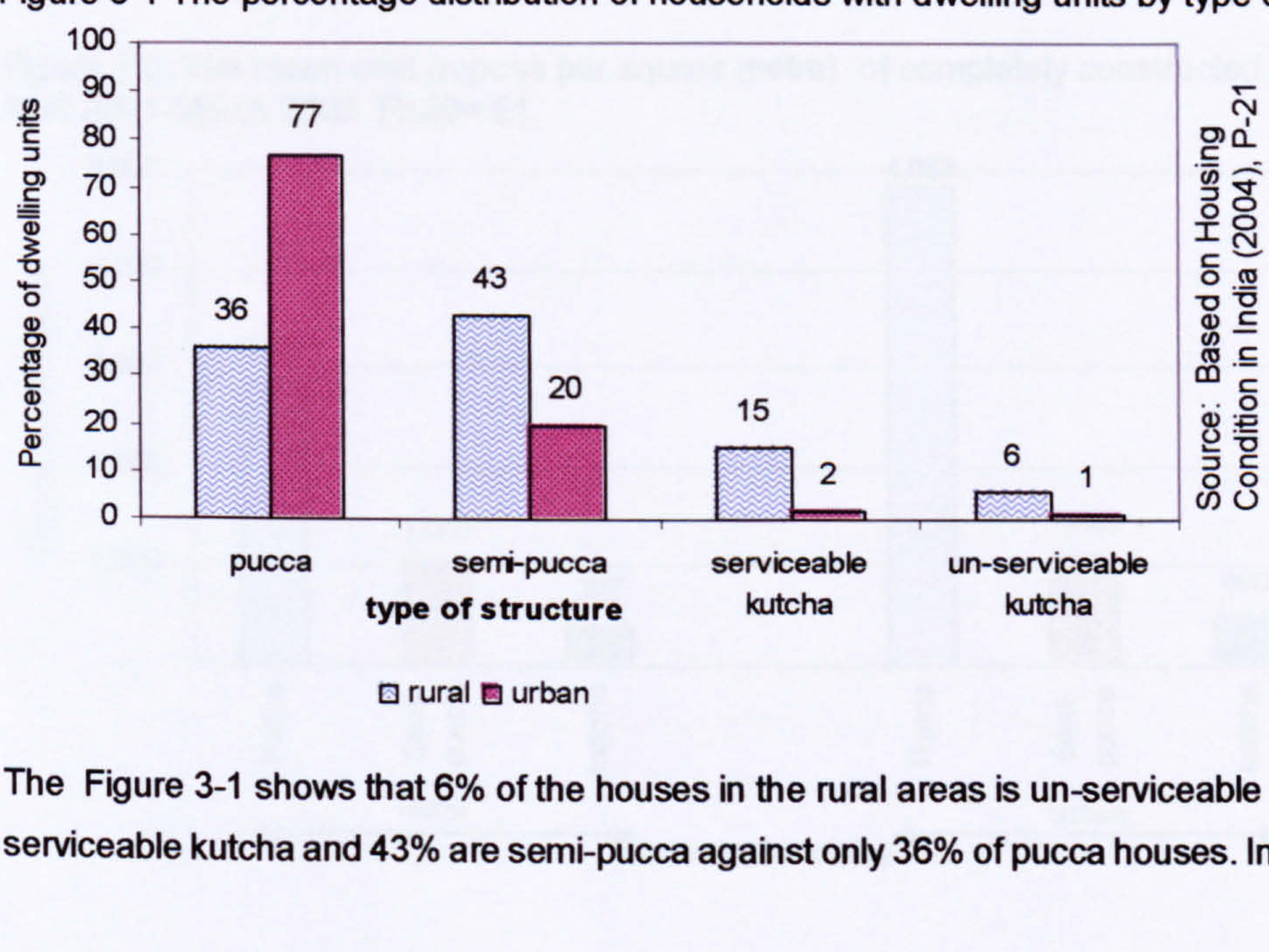
Before taking up the need assessment of housing, it is important to know the commonly accepted terms to understand the different types of shelters. According to the Tenth Five Year Plan, the existing housing stock in India is categorised into four, viz., Pucca, Semi-Pucca, Kutcha, Non-serviceable kutcha units. The pucca structures are those having walls and roof (at least) made of materials such as cement, concrete, oven bricks, stone, stone blocks, jackboards (cement plastered reeds), iron and other metal sheeting, timber, tiles, slate, corrugated iron, zinc or other metal sheets, asbestos cement sheet, etc. The Kutcha structures have walls and roof made of un-burnt bricks, bamboo, mud, grass, leaves, reeds and/or other thatch. Most of the remaining houses are put under semi pucca units, in which, the walls are pucca and the roofs are kutcha. However, taking into account of the stage of dilapidation and repairs, those units having both kutcha walls and roofs have been classified as non-serviceable kutcha units.

It is important to now look at the present housing situation. It may be noted that there are several sources of estimates for the housing shortage in India, which vary from each other owing to the differences in assumptions and methods of calculations. National Building Organisation's Handbook of Housing Statistics Part-I, (NBO, 1996) and Building Materials and Technology Promotion Council and Symbiosis of Technology, Environment and Management (BMTPC, STEM, 2000) are some of the sources which provide data on housing in India. In this chapter we shall adopt the data on the housing needs based on the latest source; Housing Condition in India (2004) published by the Ministry of Statistics and Programme Implementation, Government of India. It is a detailed document that explains the process of sampling and surveying and hence, the following need assessment of housing has been based on this.

The average number of household members is 5.15 in rural areas and 4.47 in urban areas. Out of every 100 structures surveyed, 19 in rural areas and 11 in urban areas are in bad condition and required immediate major repair, which is about thirty percent of the total housing stock in India. The survey recorded that a rural household, on an average, spent about Rs.113,000 (£1,413) in constructing a new pucca house, which has an average floor area of 42 square metres (Housing Condition in India, 2004: 50). The cost of repair of a pucca house in the rural areas with an average floor area of 29 square metre is about Rs.21, 000 (£263). The households living in urban areas other than the slums, on an average, spent about Rs.263,000 (£3,288) to construct a new pucca dwelling unit, which has an average floor area of 53 square metres (Housing Condition in India, 2004: 50). According to the survey data, more than 70% of the expenses were on materials alone in all types of structures. Another 21% of the expenses were for the labour involved in the construction

During the survey, it has been observed that almost all households (99.91%) had some kind of dwelling unit for living and the proportions of households which did not have a dwelling unit for living was 0,09%. They lived under bridges, in pipes, under staircase, by the roadsides, etc., which are liable to be removed at any moment. From the description it appears that most of these people live in the urban areas. There is no data on the household size of these people in the Housing Condition in India (2004). However, by assuming the urban average of 4.47 persons per household it can be said that 921,114 shelter less people will need 206,066 dwelling units. This is an approximation since the average household may be smaller than this figure. The following paragraphs analyse the housing conditions in India based on the Ministry of Statistics' report published in March 2004 (Housing Condition in India, 2004).

Figure 3-1 The percentage distribution of households with dwelling units by type of structure



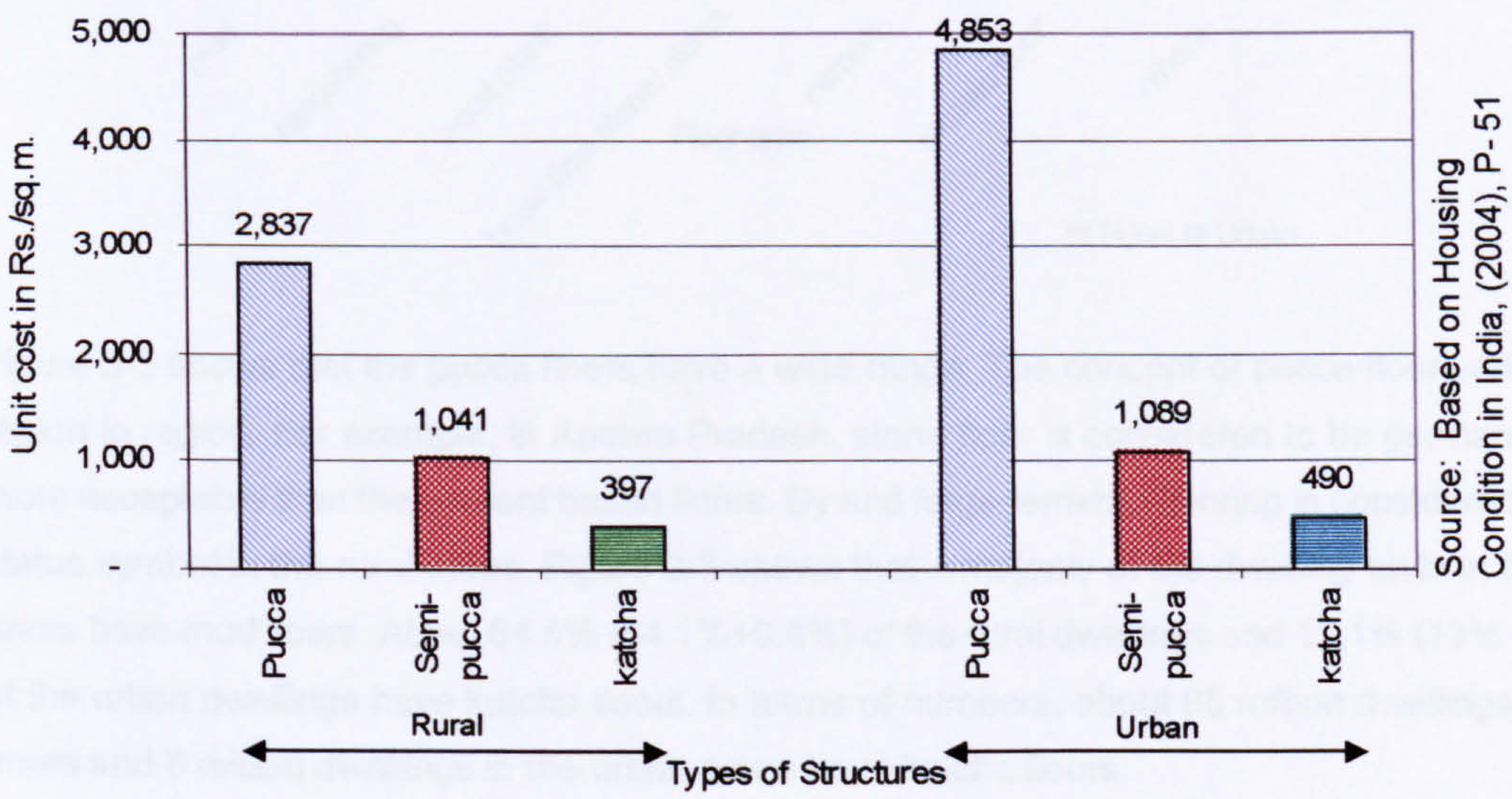
The Figure 3-1 shows that 6% of the houses in the rural areas is un-serviceable kutcha, 15% is serviceable kutcha and 43% are semi-pucca against only 36% of pucca houses. In contrast, 77% of the total urban dwelling units are pucca and only 1% is un-serviceabel kutcha. In terms of the actual numbers, 31.44 million houses (21.99+9.45) in the rural areas are kutcha and unserviceable kutcha as shown in Table 3.5. The percentage of pucca and semi pucca housing stock has increased from 1996 to 2002 (Table 3.5).

Table 3.5 The change in percentage of all four categories of structures between 1996 and 2002.

	NBO 1996		2002			
	Dwelling units in millions		Dwelling units in millions		% increase or decrease	
Structure type	Urban	Rural	Urban	Rural	Urban	Rural
Pucca	28.73	34.11	44.92	53.06	36.04	35.72
Semi-pucca	6.99	39.80	11.63	63.38	39.90	37.20
serviceable kutcha	3.80	37.07	1.40	**21.99**	-171.34	-68.61
un-serviceable kutcha	1.14	10.30	0.50	**9.45**	-128.83	-8.94
not reported	Not mentioned	Not mentioned	0.07	0.17		
		Total	**58.52**	**148.05**		
	Source: Based on NBO (1996), P 64-68		Source: Based on Housing Condition in India, (2004), P-A-76			

From the above table it is apparent that the main area of concern is the unserviceable kutcha in the rural areas where the percentage decrease is 8.94 only. Although the serviceable kutcha has been reduced by about 68 % in rural areas, it is still very high (about 22 million). At this point it may be important to look at the cost of construction of the different types of structures. Figure 3-2 shows the construction costs per unit floor area.

Figure 3-2: The mean cost (rupees per square metre) of completely constructed new building : April 2001-March 2003. Rs80= £1.



The mean unit cost of construction in the rural areas is Rs.2,837 (£35.5) per square metre, which is Rs.4,853 (£60.7) per square metre in urban areas (Housing Consition in India, 2004: 51). Such differences in unit cost of construction are primarily owing to the difference in specifications of the walls and roofs, e.g., 12 million (21%) dwellings in the urban areas have mosaic floor as against 4 million (3%) in the rural areas (Figure 3-3).

In the context of housing in India, one would certainly like to know the shortage in dwelling units for the households. However, it may be more realistic to calcute the financial implications to bring the dwelling uints to the standard of pucca structure as defined by the Tenth Five Year Plan. Field experience of Andhra Pradesh Primary Education Project and Orissa Health Project revealed that people aspire to have a pucca structure and preferably a reinforced cement concrete roof. The following paragraphs describe the conditions of the existing housing stock's flooring, walling and roofing systems. There is no information on the type or condition of the foundations and hence, it has been excluded from the discussion.

Figure 3-3 The percentage of households by floor type of the dwelling unit; all states and union territories of India.

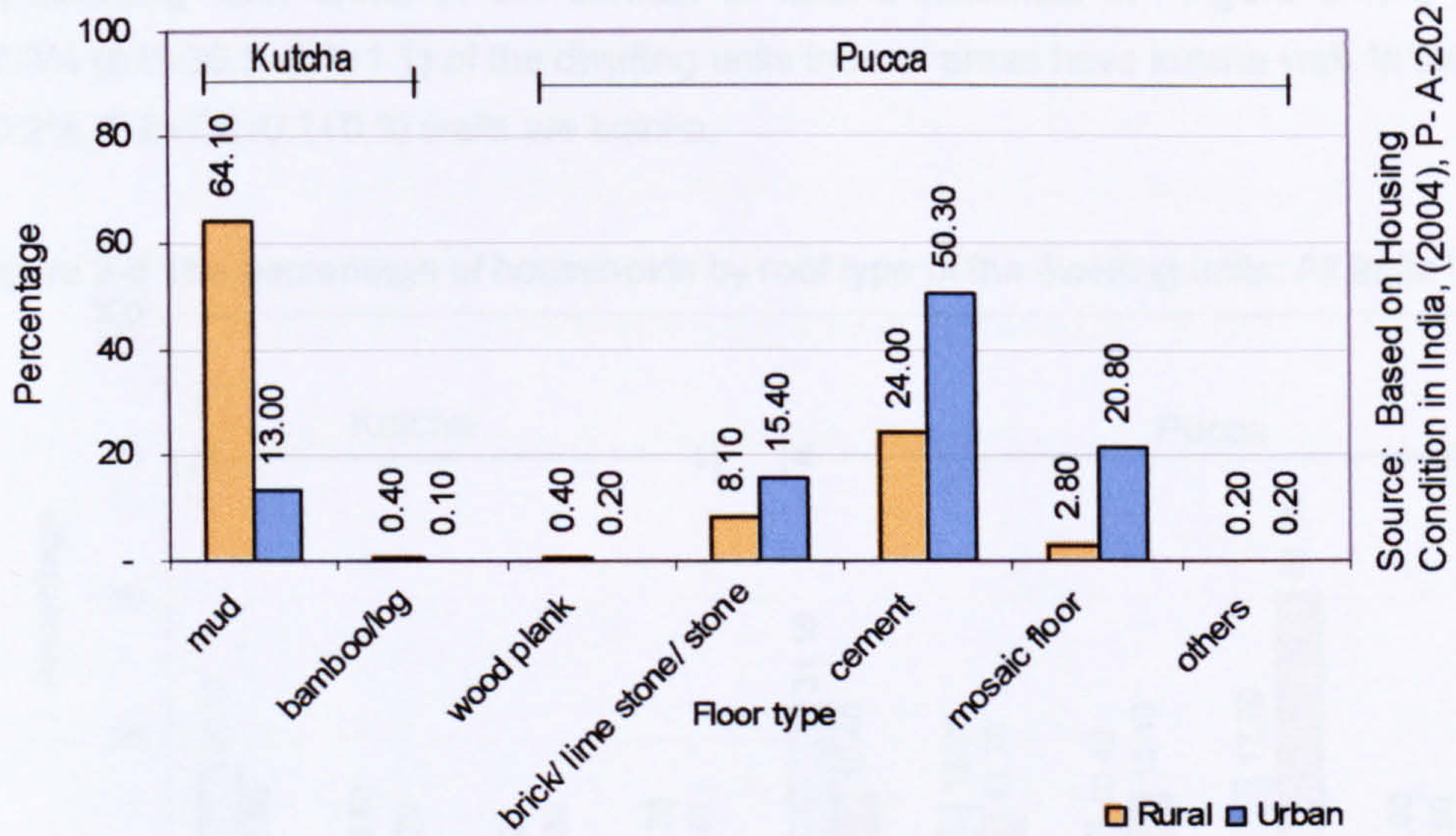


Figure 3-3 shows that the pucca floors have a wide range. The concept of pucca floor varies from region to region. For example, in Andhra Pradesh, stone floor is considered to be permanent and more acceptable than the cement based floors. By and large terrazzo flooring is considered to be a status symbol in the rural areas. Figure 3-3 shows that a majority of the dwelling units in the rural areas have mud floors. About 64.5% (64.1%+0.4%) of the rural dwellings and 13.1% (13% + 0.1%) of the urban dwellings have kutcha floors. In terms of numbers, about 95 million dwellings in rural areas and 8 million dwellings in the urban areas have kutcha floors.

Figure 3-4 The percentage of households by wall type of the dwelling unit: Urban + Rural.

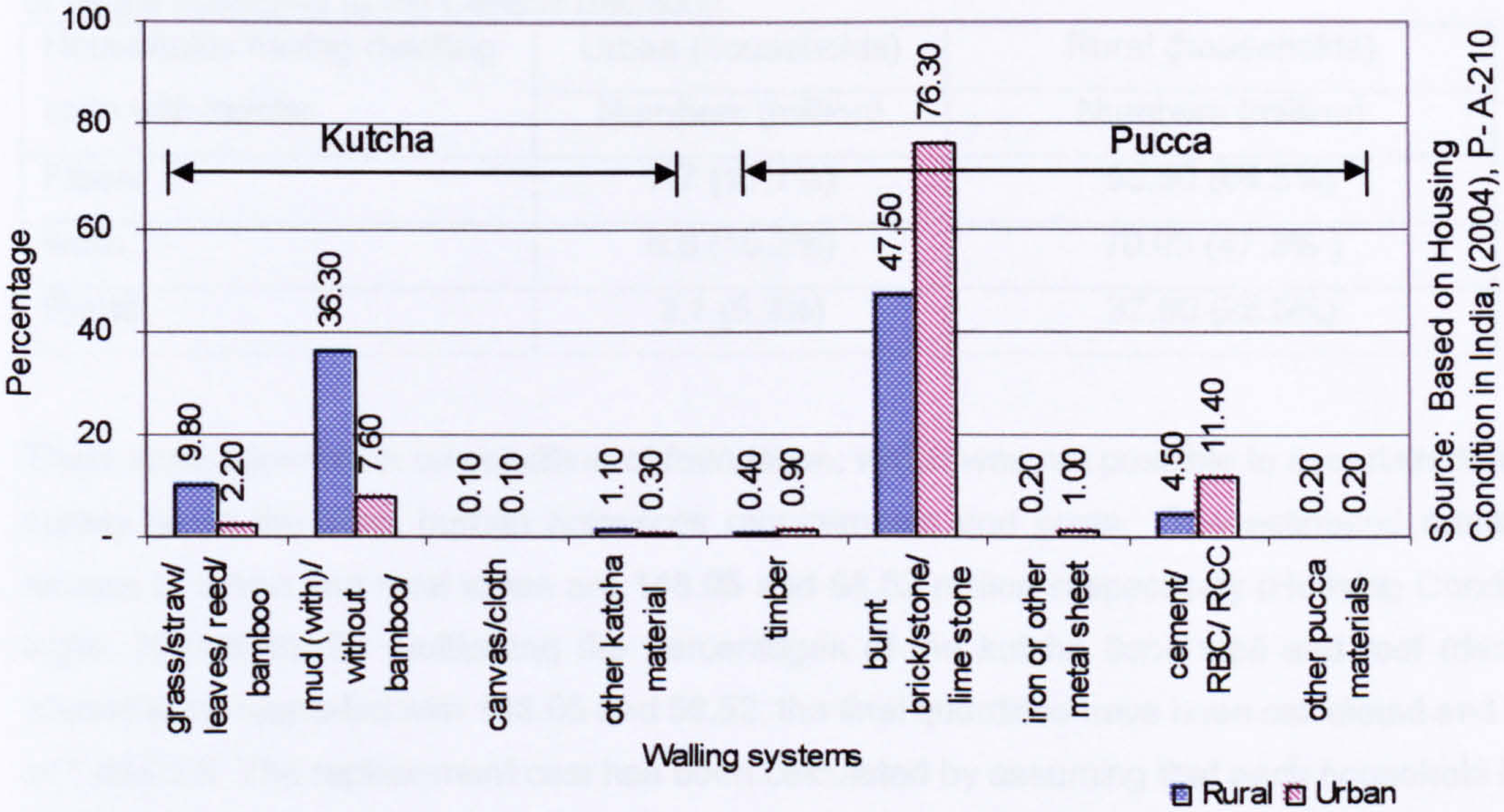
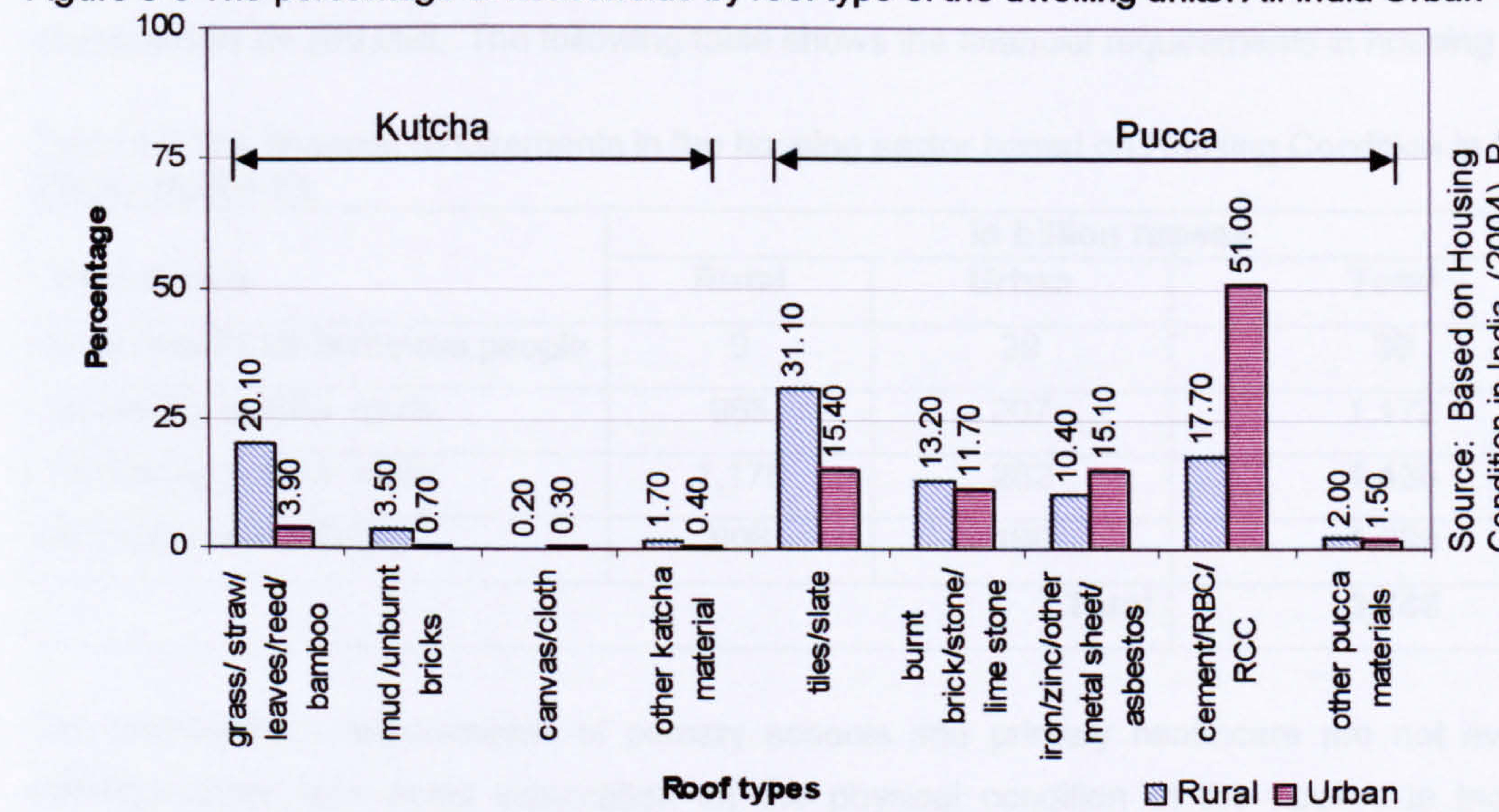


Figure 3-4 shows that many people in India live in shacks. By adding the values of the bars representing rural areas in the domain of kutcha materials in Figure 3-4, it is found that 47.3% (9.8+36.3+0.1+1.1) of the dwelling units in rural areas have kutcha wall. In the urban areas 10.2% (2.2+7.6+0.1+0.3) walls are kutcha.

Figure 3-5 The percentage of households by roof type of the dwelling units: All India Urban + Rural



Similarly, by adding the values of the bars representing rural areas in the domain of kutcha materials in Figure 3-5, it is found that 25.5% (20.1+3.5+0.2+1.7) of the rural dwellings have kutcha roof. In the urban areas 5.3% (3.9+0.7+0.3+0.4) roofs are kutcha.

Table 3.6 The overall requirement of upgrading the dwelling units in India to bring them to the level of pucca according to the Census definition.

Households having dwelling units with kutcha	Urban (households)	Rural (households)
	Numbers (million)	Numbers (million)
Floors	7.7 (13.1%)	95.50 (64.5%)
walls	6.0 (10.2%)	70.03 (47.3%)
Roofs	3.1 (5.3%)	37.80 (25.5%)

There is no information on condition of foundation, which was not possible to ascertain during the survey given the time, human resources requirements and costs. The estimated numbers of houses in urban and rural areas are 148.05 and 58.52 million respectively (Housing Condition in India, 2004:A76). By multiplying the percentages of the kutcha floor, wall and roof (described above) to be upgraded with 148.05 and 58.52, the final quantities have been calculated and shown in Table 3.6. The replacement cost has been calculated by assuming that each household lives in 35 square metre in rural areas and 43 square metre in urban areas and the average costs of such units have been Rs.73,000 (£913) and Rs.191,000 (£ 2,388) (Housing Condition in India, 2004: 52, 53).To have a very approximate estimation, it has been assumed that the replacement cost of roof, wall and floor finish will be 35%, 23% and 13% respectively of total cost as shown in section 5.3.1 of chapter 5 on Andhra Pradesh Primary Education Project. The dwelling units for the shelter less people, i.e., 0.091% of the total population are to be built in the urban areas (as explained before). The average urban household size being 4.47, the total number of dwelling units for the shelter less people would be 206,066. The following table shows the financial requirements in housing sector.

Table 3.7 The financial requirements in the housing sector based on Housing Condition in India (2004). Rs80= £1.

Description	**In billion rupees**		
	Rural	**Urban**	**Total**
New houses for homeless people	0	39	39
Replacing kutcha roofs	965	207	1,172
Replacing kutcha walls	1,176	262	1,438
Replacement of floors	906	190	1,096
		Total	**3,745**

The maintenance requirements of primary schools and primary healthcare are not available. Although there is a detail information on the physical condition of the houses in India, the maintenance requirement has been excluded in this chapter to maintain consistency with the primary education and primary healthcare. Therefore, the bare minimum financial requirements in the field of primary education , primary health care and housing according to the Tenth Five Year

Plan (2002-2007) and Housing Condition in India (2004) are as follows.

Table 3.8: The approximate immediate need for Basic Minimum Services

Sl no	Description	Requirement (billion rupees)	% of total
1	Housing	3,745.00	94.76
2	Primary Education	202.00	5.11
3	Primary Health care	5.13	0.13
	Total	**3,952.13**	

** £1 = Rs.80, i.e., £49.41 billion (2004)

Table 3.8 shows that the share of financial requirements of housing in basic minimum services is 94.76% followed by primary education with a huge difference of 89.65%. The Government of India has the provider's role in primary education since it is bound by the Constitution, which says that every child/citizen of this country has a right to free education until (s)he completes the age of 14 years (Ninth Five Year Plan, 1997). In a similar manner, primary healthcare is a Government's responsibility. However, in housing, the subsidy has not worked well since the coverage of the beneficiaries has been limited owing to the resource constraints; there has been high level of leakages with a large number of non-eligible beneficiaries getting houses and also owing to the fact that houses were provided free of cost had dampened the motivation of making houses under their own initiative. Considering the enormity of the financial requirement in housing, Government can act as a facilitator by framing pro-poor strategies by exploring possibilities of increasing income at household level.

3.5 SUMMARY

It may be noted that the Ninth Five Year Plan (1997-2005) aimed at supplying the basic minimum servisces, i.e., primary school, housing and primary healthcare building as a top priority in development. This could not be attained with the Ninth Plan period and hence, the Tenth Five Year Plan (2002-2007) also assigns a high priority to complete the unfinished target of the Ninth Five Year Plan. The approximate total investment for just the basic minimum services is Rs. 3,952 billion (£49.4 billion), which is 6.5 times the investment requirements of 610 billion rupees (£7.63 billion) in the construction sector (Tenth Plan, 2002-2007:39) at 2001-2002 prices. The required amount of Rs. 3,952 billion is 17.4 % of the GDP (2001-2002, projected) which is Rs.22,719 billion (£ 284 billion) (BMTPC & STEM, 2000, Table 3.3). The estimated financial requirement for providing the basic minimum services does not include the recurring maintenance cost of the existing infrastructure. Neither does it consider the deteriorated buildings that are structurally unsafe due to poor maintenance and ageing. The calculations have not considered the financial requirements on infrastructure repair and replacement owing to the natural disasters such as earthquake, flood and cyclone, which have been observed to occur quite frequently in the last few years.

The calculation carried out in this chapter shows that the financial requirement to clear the backlog of basic minimum services is huge and hence, its implications on socio-economy and environment should be examined. In the light of the discussions on sustainability in chapter 2, the investment of 3,952 billion rupees may be viewed as an opportunity for enhancing employment generation by adopting labour-intensive technologies. This will partially address the issue of poverty alleviation, the goal 1 of the Millennium Development Goals. In addition to that, the use of locally available materials and methods of construction should also be considered to increase the income multiplier effect discussed in chapter 2. It may be noted that, there is a relationship between construction activity, economic growth and economic development. According to Crosthwaite (2000) Asia is the largest regional construction market in the world. In addition, the Asian region has the largest share of GDP devoted to construction spending.

However, it is important to note that, construction materials and technologies deplete natural resources and emit Green House Gas, if produced by burning fossil fuel. Agenda 21, discussed in chapter 2, suggests that, while all States and all people should cooperate in eradicating poverty as an indispensable requirement for sustainable development, there is a need for assessing the human impacts on the environment. Therefore, an investment of 3,952 billion rupees in basic minimum services should be examined as an opportunity for adopting cost effective techniques, employment generation and also as a threat to the environment in terms of depletion of energy and emission of CO_2.

It is important that the decision makers know the quantitative aspects of socio-economic and environmenatl impacts of the investment on social infrastructure, so that they can make an informed choice. It may be noted that the cost estimates in this chaper are based on conventional method of cement and steel-intensive systems. Therefore, there is a need for exploring if there are ways of cost reduction that is labour-intensive, low embodied energy-intensive with low emission level. Therefore, the next chapter will explore the possibilities of delivering the basic minimum services in the light of international guidelines on sustainable social infrastructure development, discussed in chapter 2.

CHAPTER 4: SUSTAINABLE SOCIAL INFRASTRUCTURE DEVELOPMENT: THE CONTEXT

4.1. SUSTAINABLE CONSTRUCTION

In view of the huge financial requirements of supplying adequate infrastructure under the basic minimum services, one can wonder how the Government of India will solve this problem. It is now generally recognized that Government, in the past, tended to take on too many responsibilities, imposing severe strains on its limited financial and administrative capabilities and also stifling individual initiative (Tenth Five Year Plan, 2002-07). In this context it may be noted that according to the Tenth Plan, India's external debt was US $93.53 billion at the end of March 1998. Therefore, there is an urgent need of a search for cost effective construction technologies to reduce the cost of basic minimum services.

One of the reasons for this situation in India may be the huge population increase, which has also increased human activities. Such increased human activities, if not controlled, may take us close to the "carrying capacity". Bartlett (1998) refers to Giampietro et al (1992) and explains that the term "carrying capacity" refers to the limit of the number of humans the earth can support in the long term without damage to the environment. As described in chapter 2, Harmaajärvi (2000) suggests that to avoid this, there is a dire need for a conscious effort towards reducing the rates of consumption of resources in the context of the social infrastructure. This may be done by adopting less material-intensive systems for construction compared to the conventional cement and steel based systems, which have about 73% of total cost as material costs (Figure 4-1). There is also a need for low embodied energy-intensive materials and construction technologies that emit less pollutant to the environment. Therefore, Harmaajärvi's suggestion will not only reduce cost of construction, it will deplete less quantity of natural resources and also emit less pollutants compared to the conventional systems based on cement and steel. These actions will help in achieving sustainable development in India.

The problem of population increase, poor living condition of the people, inability to pay for the primary healthcare and education are all connected with the poverty of the people. It is estimated that, in 2012, about 130 million people will be below the poverty line in India (Tenth Five Year Plan, 2002-2007). Every effort, therefore, needs to be made to reduce the poverty rate even faster than at present. According to the Tenth Plan, a target of creating 100 million employment opportunities over the next ten years has also been announced by the Prime Minister and based on that, the immediate goal is to create 50 million employment opportunities during the next five years (2002-2007). Under such circumstances, it is important to search for construction technologies, which are more labour-intensive than the conventional cement and steel based systems. This approach, along with Harmaajärvi's suggestion may lead to sustainable social infrastructure in India. This fits into the domain of "Sustainability" described in chapter 2 based on a detail literature review on how sustainability has been interpreted by the researchers, international agencies and institutions. All these lead to the need for assessing the impacts of different options of construction technologies on the socio-economic and environmental aspects in a particular context of social infrastructure development. The key to the success lies in the trade-off among the three pillars of sustainability, viz., social, economy and environment. It is important to mention at this point that the impact assessment in this dissertation will be carried out at local level and the reason for this has been discussed below.

4.2. IMPACTS OF CONSTRUCTION AT LOCAL LEVEL

Between 1995 and 1997, resource mapping exercises were carried out in Orissa, Bihar, Andhra Pradesh, Uttar Pradesh , etc. (Das, 1997), which revealed that the rural people, traditionally, prefer to stay mostly within the district boundary. The poor conditions of roads and lack of adequate transportation are also partially responsible for this. Their social and income generation activities are also usually confined within the district. Apart from that, the major administrative levels in India are National, State and District. In this system, district is the lowest level of financial and administrative control in the Government system. We shall, therefore, examine the impact of construction within the domain of a district. This approach has been inspired by Theaker and Cole's (2001) statement that, sustainability is local – the day-to-day experience of local Government gives a more intimate experience of local conditions. Impacts of the districts could be assessed at the state levels, which will enable the national level to understand the impacts at regional level. It may be noted that some of the issues such as local materials and labour intensity have pronounced effect at local level, whereas emission of CO_2 and depletion of non-renewable and renewable energy have global impacts.

Districts in India are usually in the rural areas. It may be reiterated that, according to the Census of India (2001), urban areas are those places that fall under administrative limits of municipal corporation, municipalities, etc., or have a population of at least 5,000 and have at least 75% male working population engaged in non-agricultural income pursuits and have a population density of at least 400 per square kilometre. Rural India comprises all places that are not urban.

Let us now look into the relation between construction and the three pillars of sustainability in Indian context. The following section is a detail discussion on the socio-economic and environmental impacts of construction resulting from the current demand for of building materials.

4.2.1. Socio-economy

LOCAL MATERIALS

Construction activities generally require materials, human resources and equipment. The materials may be local, industrially produced (cement, steel) and brought from a distance by road transportation or it may be imported. The following table shows the general trend of break up of construction cost in India. Table 4.1 shows that the material component is 58-60% whereas the labour component is 11-13%.

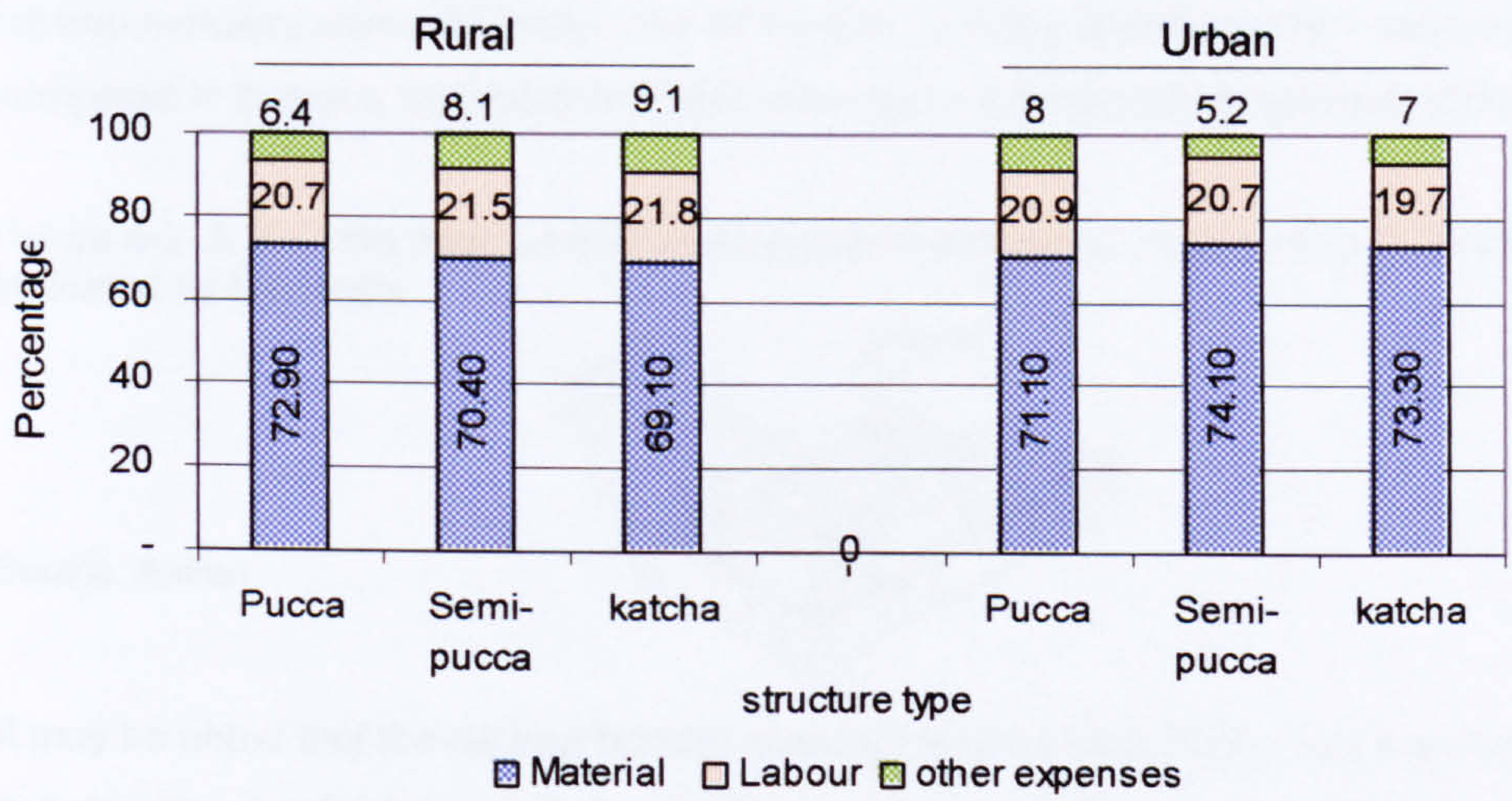
Table 4.1 Construction Costs (national average) in India

Materials %	Construction Equipment %	Labour %	Finance %	Enabling Expenses%	Admin Expenses %	Surplus %
58-60	4.5	11-13	7-8	5.5-6.5	3.5-4.5	5-6

Source: Construction Industry Development Council Survey as sited in the Tenth Five Year Plan (2002 : 847, table no-7.7.1)

However, in general, 72.9% of the total investment in a rural pucca (permanent) house construction is spent on materials (Figure 4-1). It may also be noted that the other expenses shown in the first bar from the left in Figure 4-1 is 6.4%, which is about 26% (4.5+7+5.5+3.5+5) in Table 4.1. This variation may be attributed to the fact that the rural poor adopt manual process of construction (Das, 1999) thus reducing the expenses on equipment and the other components shown in the Table 4.1.

Figure 4-1 The percentage distribution of materials, labour and other incidental costs of new construction in Urban and Rural areas (housing sector).



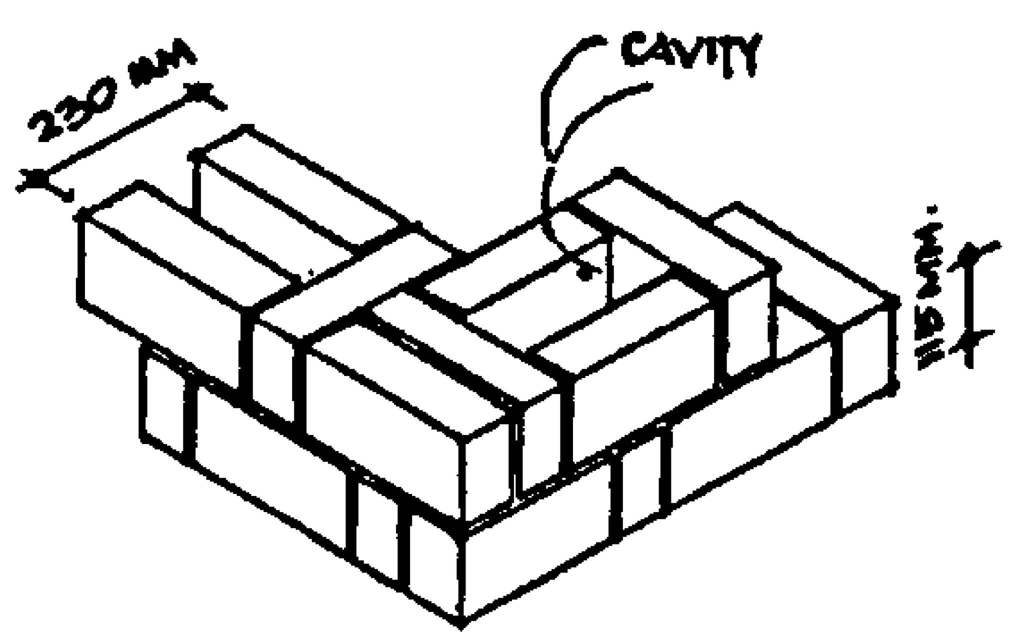
Source: based on Housing Condition in India, 2004, the statement 33, p-57.

Let us now examine how the material component in construction can be regulated. If locally available materials, e.g., brick, stone, clay tile, etc., are used in the construction, the investment on them will benefit the local material suppliers. In Ranga Reddy district of Andhra Pradesh the unit cost of a steel and cement-intensive building was Rs.2,146 (£26.83) per square metre in 1995-96. Out of that Rs.701 (£8.8) per square metre was retained within the district which is 33% of the total cost. Therefore, 67% of total investment on construction in that village of Ranga Reddy district went to the industrialists and also the industry's workers. If imported materials were used in construction, some amount of money would have gone out of the country. Therefore, use of locally available materials will benefit the local people. On this issue, one may argue that cement and steel are creating employment for some people, somewhere within the country. However, that is a separate subject of research and hence, this dissertation adopts the UNCHS/ILO (1995) suggestion of increasing employment and income-generating opportunities as a major consideration in the development such as shelter delivery. It may be noted that the National Housing and Habitat Policy (NHHP, 1998) has also recommended the use of local materials in shelter construction for generating livelihood for the poor. However, the environmental impact of the use of local materials should also be examined.

Cost Effective Construction Technologies And Labour-Intensive Systems

Let us examine the role of different construction technologies. A material may be used by adopting different methods that may have different implications on material and labour costs. For example, burnt clay bricks are traditionally used as a 230 mm solid brick wall with 1:6 cement and sand mortar, which consumes 480 bricks and about 66 kilograms of cement per cubic metre of masonry. If rat-trap bonded brick masonry with the same specifications of cement sand mortar is used to build a 230 mm thick wall, it will consume 400 bricks, and 36 kilograms of cement. Therefore, rat-trap masonry saves 80 bricks and 30 kilograms of cement for every 1 cubic metre of masonry compared to that of a solid brick wall. All these data are based on Vidyalayam (Bonner, Das, 1996).

Figure 4-2 A 230 mm thick rat-trap brick masonry wall corner. The savings in brick consumption is indicated by the cavity



Source: Author

It may be noted that the rat-trap bonded masonry is more labour-intensive than solid brick work. In constructing a solid brick wall, the total labour input is 4.84 working days whereas in a rat-trap bonded wall it is 5.61 working days (i.e., 0.77 days extra). However, the overall cost of the rat-trap bonded masonry is lower than the solid brick wall. To illustrate this, let us look at the DFID-funded Andhra Pradesh Primary Education Project's experience in 1995-96, which was an attempt to reduce the cost of school construction. Based on the Government approved rates (Standard Schedule of Rates, 1995-96) the per cubic metre cost of a 230 mm thick solid brick wall was Rs.994 (£12.43) as against Rs.899 (£11.24) for a rat-trap bonded wall. Therefore, the rat-trap bonded wall is cheaper than solid brick masonry wall. According to Bonner and Das (1996), the level of stress in a two storied load bearing rat trap wall is low (4.55 kg/ square centimetre) compared to its capacity (7.5 kg/ square centimetre). Hence, rat trap bonded wall is structurally safe.

Table 4.2 A 230mm thick rat trap brick wall is cheaper and more labour intensive than a 230mm thick solid brick wall. Rs.80= £1

Sl no	Walling type	Cost per cubic metre	Labour cost per cubic metre
1	230 mm solid brick masonry in 1:6 cement mortar	Rs. 994	Rs. 214.14
2	230 mm rat-trap bonded brick masonry in 1:6 cement mortar	Rs. 899	Rs. 248.14

Source: Author

It is, therefore, evident that, with the same material, some technologies may be more labour intensive than the others. In a similar manner construction technologies using different materials such as cement stabilised mud block, stone concrete blocks, etc., have different degrees of labour intensity as explained in the Appendix III and IV. Therefore, the technologies that are more labour-intensive may be utilised to maximize opportunities for the employment of labour (skilled and unskilled), while supported by light equipment, cost competitiveness and acceptable engineering quality standards, and timely implementation.

According to the Building Materials Technology Promotion Council and Symbiosis of Technology, Environment and Management, Bangalore (BMTPC,STEM, 2000), there is a need for 173 million tons of cement and 600 billion bricks for the period 2001-2006. Let us now examine the implications of construction technologies on the estimated requirements of cement and bricks. According to Rai and Jaising (1986) 30,000 bricks, i.e., 62.5 cubic metre of masonry work is required for the construction of 100 square metre of residential building. Therefore, with 600 billion bricks, one could construct the walls of 20 million houses each having 100 sq. m. covered area, which would consume 83 million tons of cement. However, if one adopts rat trap bonded brick masonry, one would require 25,000 bricks to construct a 100 sq. m. of covered area. Therefore, by adopting rat trap bonded masonry, 24 million houses could be produced with 600 billion bricks, which will consume 54 million tons of cement. Therefore, rat trap would not only produce 4 million additional houses, it would also save 29 million tons of cement. As shown above, in constructing every cubic metre of rat trap bonded brick masonry, 0.77 extra working days are required compared to that of solid brick work. Therefore, rat trap bonded masonry walling with 600 billion bricks will generate 2.365 billion additional working days of employment compared to solid brick wall.

In general, the local materials used in vernacular architecture in rural India are mud, stone, brick, timber, etc. For reinforced cement concrete based construction in the rural areas, cement and steel, produced industrially are transported to the villages and hence, most of the invested money goes out of the locality. Whereas, most of the money would be retained within and the neighbouring villages, if one uses local materials. Thus, it leads to a high income-multiplier effect and helps the local people to improve their condition of living.

4.2.2. Environment

The last section showed how the use of cost effective construction technologies, such as rat-trap bonded brick masonry wall, could reduce the unit cost of construction and also increase labour intensity. While some technologies are good opportunities for employment generation, they could be a threat to the environment and hence, this issue of infrastructure supply needs examination. Let us now examine the process of infrastructure construction and maintenance and their impact on the environment. It has been observed that human civilization has been rapidly using up the earth's finite resources and, to state the obvious, once these resources are used up there will be no more left. On a global scale, the simple pursuit of economic gain is openly destroying the environment (Davies, 1999).

According to Davies (1999), human activity currently uses 40% of terrestrial photosynthesis (the biological product of the land). It is only 20% of the earth's population, which is responsible for most of these activities. If the other 80% aspire to the same level of development and living standard as that 20%, then it is clear that the planet will not be able to sustain its current population at the aspired rate. Wheat (2002:16) quotes Ronnie Hall (policy maker and research officer with Friends of the Earth, UK) and states that, *"If people living in the South used as much fossil fuel as people in the UK currently do, by 2050 we would need eight atmospheres to prevent global warming."* Davies (1999) states that, the world population is forecast to double from its current 5 billion to 10 billion in the next 50 years. He states that, it has taken the whole of human history to reach 5 billion, yet it is set to double in the next 50 years. The challenge is to fulfil the growing needs and aspirations of the world's population using the available resources.

Davies suggests that the promoters of sustainable development should be alert from the beginning of the project to any possible risks to the environment and the excessive use of non-renewable and renewable resources. Based on Davies' suggestion the following may be suggested.

- reducing consumption of high-energy building products, e.g., cement, steel, etc.
- reusing waste materials - this will reduce the amount of waste polluting the environment without having any detrimental impact on the shelters and the users.
- using local materials- thus reducing consumption of fuel for transportation.

In theory, sustainable development is really about making the existing resources last as long as possible in the hope that long term solutions will be found to the problems (Davies, 1999). The next few paragraphs will discuss the issue of environment in the context of India.

It is important to note that the use of construction materials such as brick, cement, steel, etc., has detrimental effects on the environment. Every ton of cement as finished product at production centre releases approximately one ton of CO_2 into the atmosphere (chapter 8, section 8.5). Production of brick depletes coal and firewood and releases CO_2. Manufacturing, transportation, implementation and disposal of building materials and technologies usually cause damage to the environment by depleting non-renewable and renewable materials and also by polluting the environment. As mentioned in chapter 2, the construction sector is one of the largest contributors of CO_2 in India, accounting for 22% of the total CO_2 emissions (Maithel, 1999). Production of the three main construction materials, viz., steel, cement and bricks require burning of about 70 million tons of coal annually. It is important to note that the brick industry, with an estimated coal consumption of 20 million tons per year, is the third largest consumer of coal in the country after power plants and steel industry (Maithel, 1999). Apart from that, according to Deb (1994), every year the Indian brick industry utilises approximately 397 million tonnes of clay, a material that the farming communities can not afford to lose.

In states such as Orissa, Andhra Pradesh, Maharashtra, etc., coal is used as fuel in the thermal power plants, which generate fine grain ash popularly called as fly-ash. According to the Fly-ash Mission Report (1999), the power industries in India produce over 90 million tons of fly-ash per annum. Fly-ash is proving to be virtually impossible to dispose of; consequently it has become a major pollutant. To mitigate the effect of fly-ash, one has to ensure the restoration of cyclical processes in which wastes become new resources for society or nature. For the past ten years it has been common knowledge that fly-ash, when mixed with lime and gypsum, makes a strong durable building block, which has become commonly known as FAL-G, and its use in construction would greatly reduce the increasing deposit of fly-ash. Consuming these in the construction will clean up the environment. Agricultural waste such as rice husk has been used as fuel for the brick production, which is an alternative to coal and firewood.

According to Verma (2000), there has been an increasing awareness of environmental protection in India in the recent past. He states that, the Ministry of Environment and Forests, India, has brought out a notification on the 14th September 1999, restricting the excavation of top soil for manufacturing of bricks. The notification has encouraged the utilization of fly-ash in the manufacture of building materials and construction activity within a specified radius of 50 km from coal or lignite based thermal power plants. Although Verma's (2000) report indicates that there is some action to protect the environment, we still do not know about its impact based a quantitative assessment. However, according to the Tenth Plan, environmental impact does not appear to have received the due importance in India.

"ecological issues, unfortunately, have not been adequately incorporated into our development strategy, despite the fact that there has long been recognition of the importance of environmental and ecological factors in Indian planning and policy "(Tenth Five Year Plan, 2002-2007 :4).

As mentioned earlier, technologies regulate the extent of impact on enviroment since different technologies use different types and quantities of materials. To illustrate this, the section 4.2.1 has shown that, if rat trap bonded brick masonry is used for constructing houses with 600 billion bricks, it will save 29 million tons of cement compared to that of solid brick masonry. Such reduction in cement consumption would save on depletion of non renewable natural resources and also produce 29 million tons less CO_2 than solid brick masonry. Apart from these, rat trap saves bricks (as mentioned before) and hence, would also have less environmental impact.

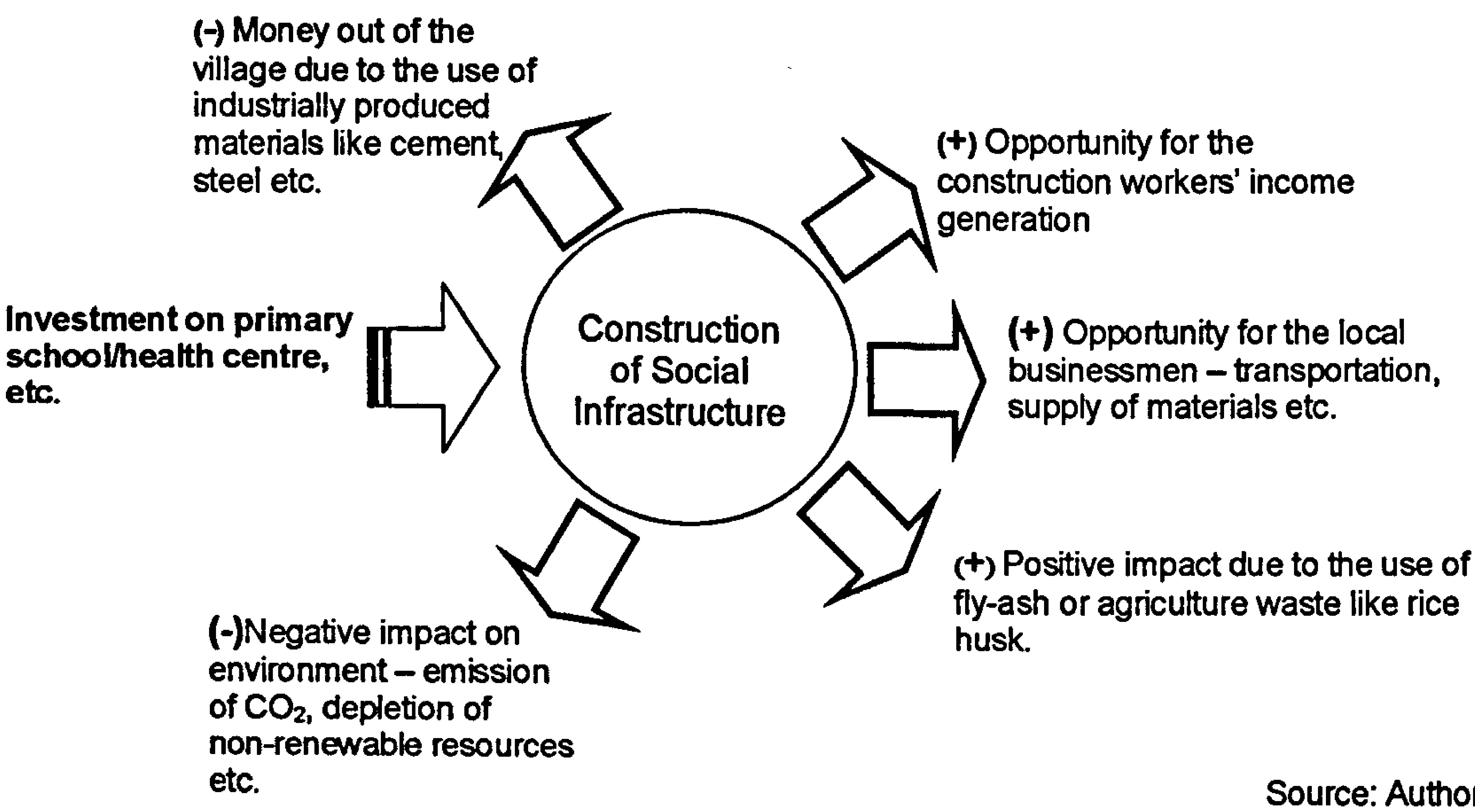
The quantities of impacts of different construction technologies on environment discussed above will enable a decision maker to choose the sustainable option in a context. However, one may raise a question whether we are overlooking employment opportunities while emphasising environment. The answer is – perhaps not. It has been observed that this emphasis on environment does not necessarily reduce employment opportunities significantly, e.g., Donovan et al (1997) state that the imposition of carbon emissions (or indeed any other policy changes) does not raise un-employment above the so-called natural level of unemployment for any economy.

Socio-Economic And Environmental Impacts Of Construction At Local Level

The policies and programmes such as the National Housing and Habitat Policy, Government of India (NHHP, 1998), Tenth Five Year Plan (2002-2007), etc., may not be adequate to address the issues of sustainable social infrastructure construction. It may be argued that such top-down approach may not be sufficient to get the best out of the context. There is a need for bottom-up approaches based on actual project experience to complement the policies and programmes. In view of this, the following diagram summarises the above discussion on how construction can be a socio-economic opportunity and also a threat to the environment in the domain of a district.

Figure 4-3 shows that, when social infrastructure such as primary school, health centre, etc., are constructed in a district, an amount of money goes out of the locality because of the use of cement, steel, etc., which are not locally produced. One can reduce this leakage of money from the district by adopting local materials and methods in construction, which will benefit the construction-related local people. Figure 4-3 shows that, materials and methods of any construction will have impact on the environment in terms of depletion of non-renewable and renewable energies and emission of CO_2. Therefore, while construction could be beneficial (indicated as "+") to the local context in some respects, it may have detrimental (indicated as "-") effect as well. Therefore, as discussed in chapter 2 (Lippiat and Boyles, 2001), the answers lies in the trade-offs between positives and negatives of the Figure 4-3.

Figure 4-3 The investment on construction could be an opportunity for livelihood and a threat to environment as well.



Source: Author

However, it is only a theory. Therefore, there is a need for examining this diagram with respect to grass root level experiences. With respect to the above diagram let us now conduct an in-depth examination into the impact of construction on the local context. We shall demonstrate this with the field experience of Orissa Primary Health Centre construction, which was based on the experience of Andhra Pradesh primary Education Project (discussed in chapter 2).

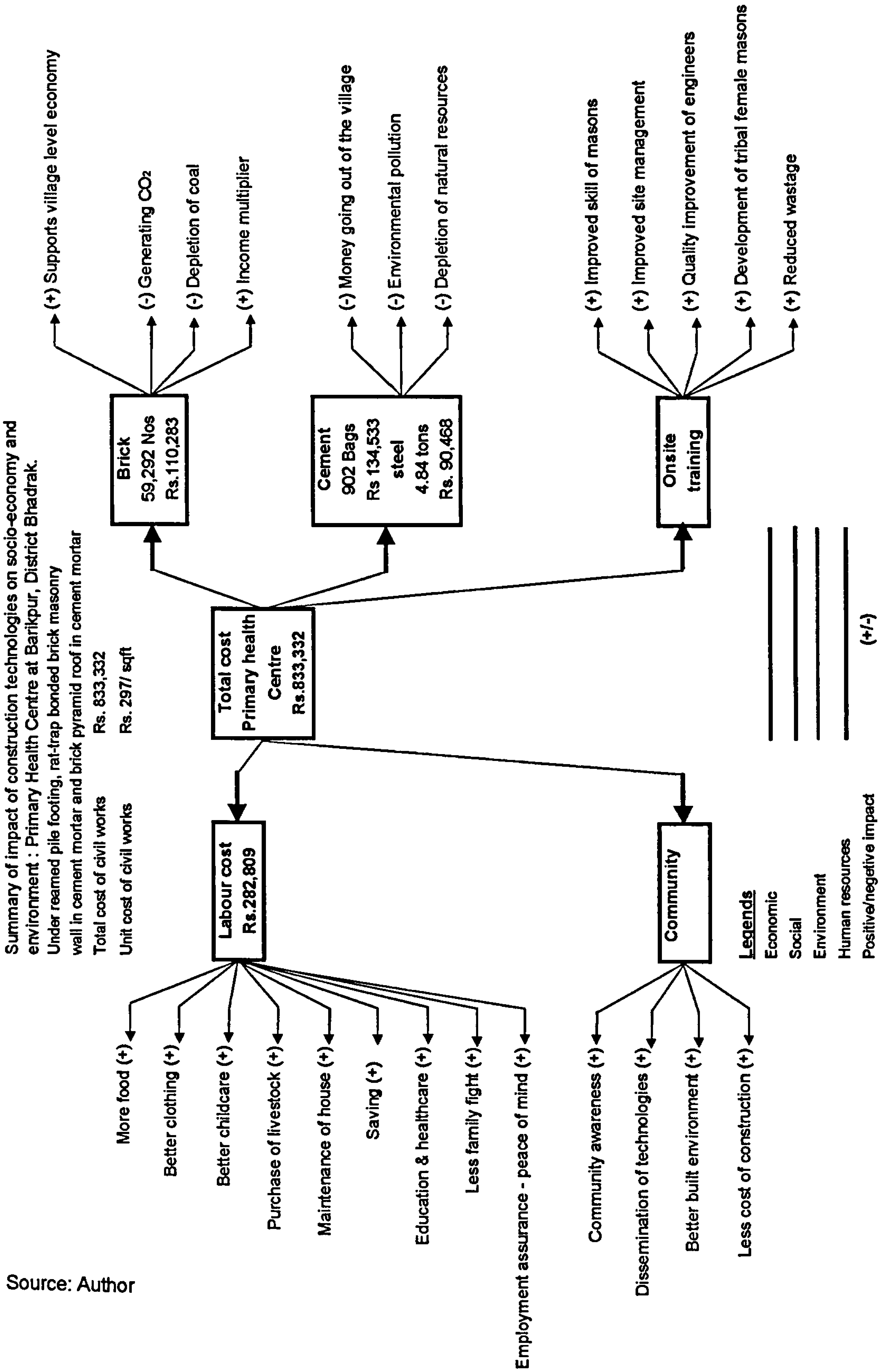
4.3. FIELD EXPERIENCE OF THE IMPACTS

In chapter 2, the domain of sustainable social infrastructure development in India has been identified after a detail literature review. Figure 4-3 shows this domain in terms of more specifics, e.g., the positive and negative impacts of different construction technologies on local level employment generation, depletion of non-renewable and renewable energies and emission of CO_2. We shall now raise a few questions regarding the quantitative information on these impacts under the attributes shown in Figure 4-3. For example, under the attribute "Opportunity for the construction workers' income generation", do we have information on how much money actually goes to the construction workers if a particular construction technology is adopted in a project? Also, do we know what the workers do with the increased income at family level? This will help to understand the actual impact of different construction technologies at grass-root level. For this, we shall look into a DFID-funded project in Orissa, an Eastern State in India.

DFID has been providing financial assistance to the Government of India's social infrastructure programmes in primary education and healthcare facilities. The DFID-funded social infrastructure programmes in India emphasised the use of local materials and skills to reduce the cost of construction, increase employment opportunities, and reduce transportation cost and depletion of fuel and minimise harmful emissions. In all their projects, local materials and labour intensive technologies were adopted based on resource mapping. Under these projects, a few groups of masons were identified at each site and trained. On an average, a group of five skilled masons and ten helpers were engaged for eight months to complete the construction works at each site. During the implementation of the projects, the masons' activities were recorded meticulously, e.g., whenever a mason bought livestock or deposited some money in the bank, the site supervisors recorded it (Das, 1999).

Figure 4-4 shows the impacts of constructing a primary health project at Barikpur, Orissa, under the five major heads, viz., Labour(priority reduces from the top to bottom), community, brick, cement and steel and onsite training. The arrows from these five heads show the next level of impacts. For example, the arrows from the rectangle representing "Labour cost" show the subsequent impact at the construction workers' family level, i.e., "More food", "Better clothing", etc. Figure 4-4 is the next layer of the diagram in Figure 4-3 showing the positive impacts (marked "+") and negative impacts (marked "-") at district level. Let us now look at the quantitative aspects of the impacts at Barikpur.

Figure 4-4 The socio-economic and environmental impacts of brick intensive primary healthcare facilities at Barikpur, Bhadrak, Orissa, at local level. Rs.80= £1



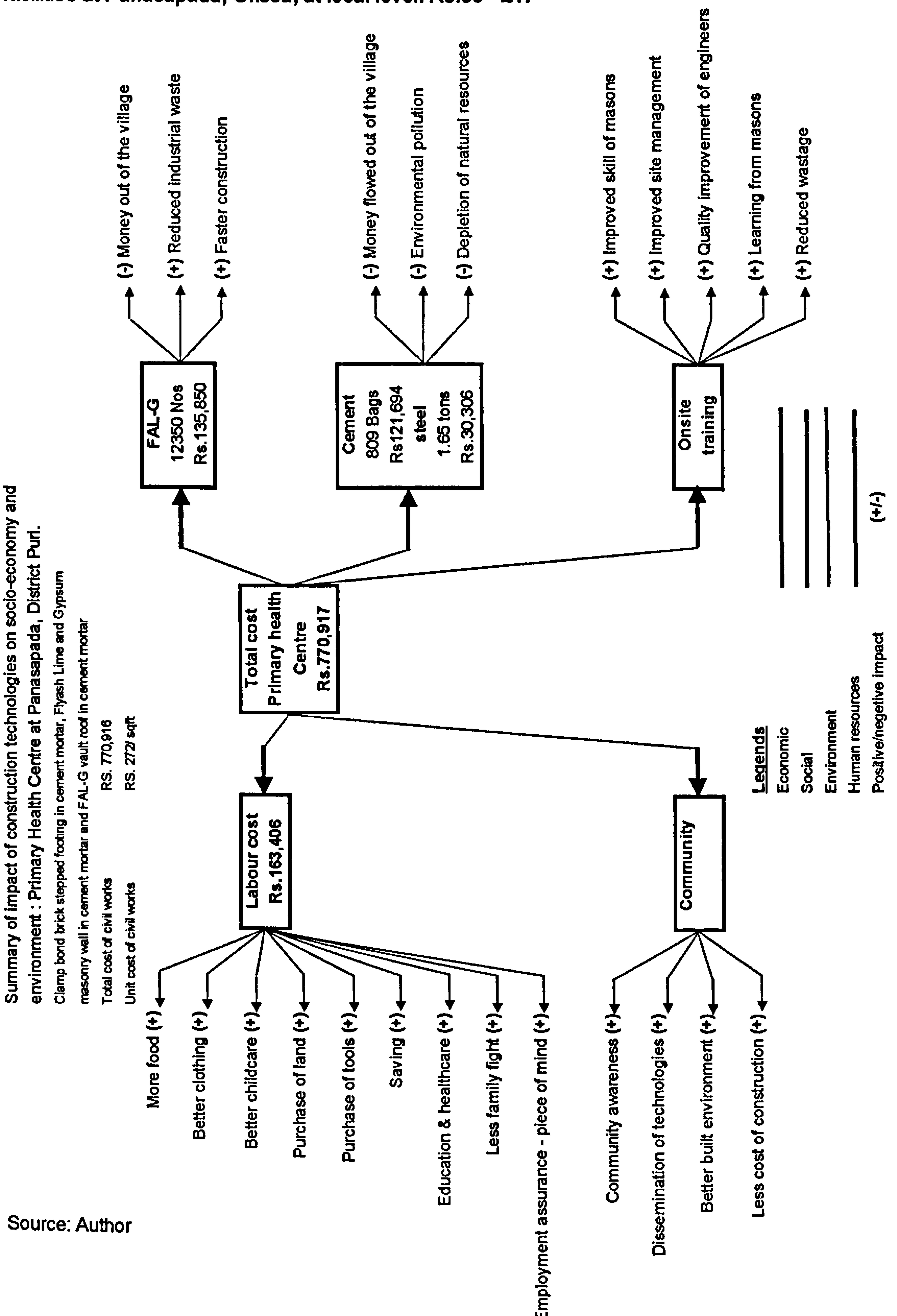
Source: Author

Barikpur is on the national highway number 5, connecting Calcutta and Madras. There were many brick kilns on the banks of the local river that produced bricks of a strength of 75-100 kilogramme per square centimetre, which was well above the minimum strength of 35 kilogramme per square centimetre, recommended by the Bureau of Indian Standard code on masonry (IS 1905 -1980). Brick was the most affordable and easily available local material and hence, rat-trap bonded brick wall and corbelled brick pyramid were adopted in the buildings (for details of corbelled pyramid refer to Appendix IV). It may be noted that the labour component of rat-trap bonded brick masonry is higher than solid brick masonry (Table 4.2). Figure 4-4 shows that the use of materials like cement and steel in construction at Barikpur had contributed more to the problem of environmental pollution and depletion of natural resources as raw materials. A major portion of investment on cement and steel went out of the district to the transporters, manufacturers, etc., since these materials were brought from outside the district boundary. Investment on local materials such as brick increased retention of money within the district boundary and thus led to a higher income-multiplier effect. However, it may be noted that brick making leads to depletion of coal and firewood, and emission of CO_2. The issue of loss of top soil is not applicable in Barikpur since clay from river is used in brick manufacturing. Barikpur being close to the Bay of Bengal, the river required regular dredging to maintain its navigability, since, high tide brought in the silt and sand.

As mentioned before, labour-intensive technologies were adopted in the construction projects and the impacts of additional income on the workers' pattern of living were documented. Interviewing the construction workers at Barikpur revealed that, whenever they had a steady income from the construction site, they spent more on food. This was followed by spending on better clothing, child care and purchase of livestock. Priority on healthcare and education appeared to be low perhaps owing to the lack of facilities and awareness. It may be noted that such observations can not be generalised. For example, Morse et al (2000) analysed the pattern of family expenditure at Eroke, a village in the Federal Republic of Nigeria. The analysis revealed that healthcare (including medicine), food and school fees respectively constitute the three major items of expenditure as agreed by males and females at Eroke. Apart from food, the villagers in Eroke lay great importance on healthcare and education. In Barikpur, these two were of low priority.

Let us now look at another project at Panasapada, which is a small village close to the Bay of Bengal. Panasapada is about 100 kilometres from Bhubaneswar, the capital of Orissa, India. Figure 4-5 shows the impacts of constructing a primary health project at Panasapada under the five major heads, viz., labour, community, FAL-G, cement and steel and onsite training. The arrows from these five heads show the next level of impacts similar to that of Barikpur. Figure 4-5 is the next layer of information of the diagram in Figure 4-3, showing the positive impacts (marked "+") and negative impacts (marked "-") at district level.

Figure 4-5 The socio-economic and environmental impacts of fly-ash intensive primary healthcare facilities at Panasapada, Orissa, at local level. Rs.80= £1.



Source: Author

Fly-ash lime and gypsum (FAL-G) blocks were found to be the cheapest option for constructing walls and roof at Panasapada. Apart from being low cost, the use of these blocks was intended to set an example of cleaning-up pollutants, such as fly-ash, which is a detrimental waste from thermal power plants. The disadvantages of cement and steel were the same as in Barikpur. There was a small variation in masons' priority of spending (priority reduces from the top to bottom in Figure 4-4 and Figure 4-5). While the first three priorities of the construction workers at Panasapada remained the same as Barikpur, the fourth was purchase of land and the fifth was purchase of tools.

Figure 4-5 shows the impact of fly-ash-intensive technologies on unit cost; income generation and environment at micro-level while constructing a primary health project at Panasapada. Figure 4-4 shows that the project cost of the primary health centre at Barikpur was 0.83 million rupees (£0.01 million) with labour cost of 0.28 million rupees (£0.0035 million) against 0.77 million rupees (£0.009 million) and 0.16 million rupees (£0.002 million) respectively at Panasapada (Figure 4-5). Therefore, while Panasapada was less expensive than Barikpur, the latter was more labour-intensive than the former.

The experience of healthcare facilities construction at Barikpur showed that the use of local materials and labour-intensive technologies can retain a greater share of investment on construction compared to steel and cement based systems. Figure 4-4 and Figure 4-5 have shown the pattern of use of the money earned by the construction workers' families. The local brick field owners, transporters, etc., have also earned money from the project at Barikpur. When these people spend their earnings on food, clothing, medicine, etc., it leads to income-multiplier effect. In Barikpur and Panasapada, the construction workers hardly saved money nor did they pay taxes and spent money on imported items. This situation is similar to the observations by the UNCHS/ILO (1995), which states that the lower-income workers tend to have lower marginal propensities to import, pay tax or save than higher-income workers, as a result the multiplier would be greater, ceteris paribus, for investments involving low-income labour. Therefore, the multiplier effect is likely to be two (as mentioned in chapter 2).

While some of the impacts shown in Figure 4-4 and Figure 4-5 are important at village level, the issues such as the depletion of coal, CO_2 emission, etc., are relevant in the global level. Rat-trap bonded masonry walling adopted in Barikpur reduced the consumption of bricks from 75,000 (in solid wall) to 60,000 thus reducing the depletion of coal and emission of CO_2. The use of 12000 fly-ash blocks in Panasapada for a covered area similar to that of Barikpur has consumed the industrial waste and emitted CO_2 for transportation only.

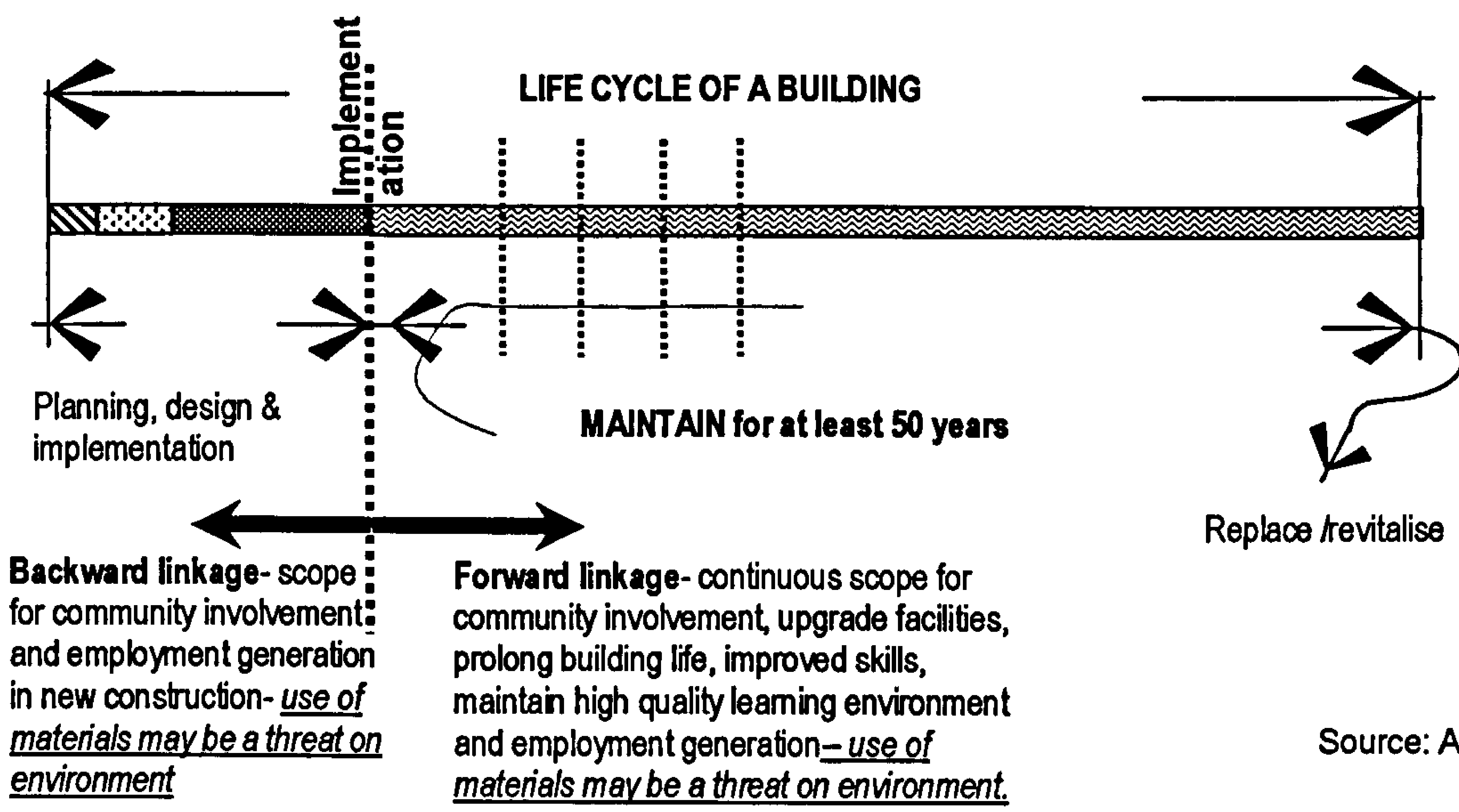
These two examples have demonstrated the extent of impact of different materials and construction technologies on cost, livelihood generation and environment in the contexts of Barikpur and Panasapada. From the above discussion, it is evident that there are some construction technologies that reduce cost of construction, increases income generation of the construction workers and, by using local materials, create higher income multiplier effects. However, any construction will affect the environment. Some technologies may be cost effective and also generate more livelihoods but cause harm to the environment. Figure 4-4 and Figure 4-5 show that the opportunities and threats of infrastructure in the contexts of Barikpur and Panasapada are primarily regulated by the technologies and are location-specific. The technologies such as rat-trap bonded brick masonry walls are environment-friendly since they consume fewer bricks and less cement than the conventional solid brick masonry walls. However, fly-ash lime and gypsum blocks are even more environment-friendly than rat trap since they consume the harmful waste (fly-ash) from the coal-based thermal power plants. The radio-activity of fly-ash, tested at the Institute of Physics, Orissa, revealed that it was safe for human (Das, 1999).

It may be reiterated that the domain of sustainable social infrastructure development in India has been shown in Figure 4-3, based on the literature review in chapter 2. Figure 4-4 and Figure 4-5 demonstrate some of the impacts of brick-intensive and fly-ash intensive technologies at grass-root level for new construction, which is the second layer of Figure 4-3. However, it is to be noted that a technology with an initially favourable socio-economic and environmental impacts, need not necessarily be so in its entire life span. An initially cost effective technology may have a high recurring maintenance cost. A building, once constructed, requires routine maintenance in terms of cleaning, painting and minor repair. As the building grows old, it needs corrective maintenance. Therefore, one should look at the life cycle implications of technologies rather than only for new construction. It is important to note that a building is a continuous opportunity for income generation and threat to the environment in its entire life cycle and hence, the following section will examine this aspect. To carry out life cycle assessment, one needs reliable database on periodic maintenance of different construction technologies.

4.4. LIFE CYCLE IMPLICATIONS OF INFRASTRUCTURE

Figure 4-6 illustrates the life cycle of a physical facility, which consists of two parts. The first part is planning, designing and implementation until a building is constructed. The second part consists of maintenance of a building for at least 50 years and eventually replacing it with a new structure. However, inadequate maintenance may lead to premature replacement of buildings. Figure 4-6 shows that the opportunity for employment generation and threat on the environment is a continuous function in the whole life cycle of a building and hence, the impacts should be assessed for both forward and backward linkage. We have already examined the issue of construction as an opportunity for income generation and also as a threat to the environment for the backward linkage. In this section we shall examine maintenance as a similar opportunity and threat in the forward linkage also.

Figure 4-6 The opportunities and threats during the entire life cycle of a building based on community based primary school construction and repair in Ranga Reddy district, Andhra Pradesh.



Source: Author

We shall discuss the life cycle implications with reference to a DFID-funded research project that aimed at understanding the maintenance aspects of primary education infrastructure in the state of Andhra Pradesh.

Table 4.3 The replacement requirement of primary school in Andhra Pradesh

Age of classroom	Numbers	Year of replacement	
		With maintenance	Without maintenance
0-5 years	16,414 (20%)	2043-2048	2028-2033
6-15 years	24,622 (30%)	2033-2042	2018-2027
16-35 years	41,036 (50%)	2013-2032	1998-2017
Total	82,072		

Source: Imran, (1999), Figure-1, page-8.

The above table assumes that the design life of a building, with regular maintenance is 50 years. The same without maintenance is about 35 years. Imran (1999) observed that the poor conditions of the schools affect the efficiency of classroom activities and perhaps enrolment and retention. Imran (1999) calculates the life cycle cost of the school buildings with and without maintenance. Based on the Government's prevailing rates, he adopts Rs.460 (£5.75) per classroom (29.7 square metre of carpet area) per annum and works out that the maintenance fund required for the 82,072 classrooms is 38 million rupees (0.48£ million) in 1999. Assuming 21% as labour charge (shown in Figure 4-1), 8 million rupees (0.1£ million) worth of livelihood generation will be done for the construction workers. It is important to note that repair is more labour intensive (Das, 2000) than new construction. The following table shows that periodic repair of the primary education infrastructure is more cost effective than no repairs.

Table 4.4 Annual life cycle expenditure – primary schools in Andhra Pradesh

Option	Unit cost (Rs.)	Maintenance cost per year	Present worth of future expenditure*	Total cost	Building life in years	Life cycle cost per year
A	100,000	2,000	19,829	119,829	50	2396.58
B	100,000	0	0	100,000	35	2857.14

Source: Imran (1999), Figure-II, page-10.

* In order to bring all the costs to a comparable basis the future maintenance expenditure has been discounted using an interest rate of 10%. Rs.80 = £1

Let us look now at the maintenance requirements in housing sector. Based on the Housing Stock and Constructions (Housing Condition in India, 2004, table-35: A120, 121) of India, the total number of pucca houses in bad state has been calculated and shown in Table 4.5. These require urgent repair.

Table 4.5 Total number of pucca buildings in bad conditions in India according to their ages.

	Number of pucca buildings in bad conditions							
Age in years	<1	1-5	5-10	10-20	20-40	40-60	60-80	>80
Rural	-	592,205	1,480,512	2,368,818	1,924,665	1,036,358	296,102	148,051
Urban	117,042	292,605	351,126	877,816	936,337	409,647	175,563	175,563

Source : Housing Condition in India, (2004), based on the data in columns showing buildings in "bad" conditions (table:35:A-120 and A-121).

Addition of the number of buildings in the row "Rural" of Table 4.5, shows that about 8 million pucca rural houses of different ages need urgent and major repair. Instead of considering this to be a liability, the maintenance may be a good opportunity for livelihood of the local construction workers and building materials suppliers and transporters. According to the statement 31 of the Housing Stock and Constructions (Housing Condition in India, 2004: 52, 53 -all classes - column 7) the average cost of repair in the rural and urban (all) areas are Rs.7, 000 (£87.5) and Rs.23, 000 (£287.5) per unit respectively. The rural and urban mean floor areas for repair are 24 square metre and 30 square metre (Housing Condition in India, 2004:52, 53 -all classes - column 6). Based on the repair areas and costs per unit, Table 4.6 shows that 55 billion rupees (£0.69 billion) in rural area and 77 billion rupees (£0.96 billion) in urban areas are required for repairing all the existing pucca dwelling units in bad conditions in India.

Assuming the labour component of repair same as new construction (21%), labour costs of the repair of houses in bad conditions will be11.55 billion rupees (£0.14 billion) in the rural areas and 16.17 billion rupees (£0.2 billion) in the urban area (Table 4.6). Since these data were collected in 2002, we will adopt the mason's and labourer's average daily charges as Rs.195 (£2.44) and Rs.106 (£1.33) (BMTPC & STEM, 2000, table 4.12:50). Assuming one skilled mason and two unskilled workers as a repair team for a house, daily wages would be Rs. 407 (£5.1) per day. Assuming 260 working days per year as one working-year (section 10.1), the investment of Rs.132 billion (£1.65 billion) on repair would generate 0.262 million working-years for teams of one skilled mason and two unskilled workers, which is very significant.

Table 4.6 The impact on livelihood generation by alteration/ improvement/ major repair of the houses in bad conditions in India. Rs.80 = £1

	Number on units (million)	**Mean construction cost in rupees per unit**	**total cost of repair in billion Rs.**	**total labour cost in billion Rs.**	**Working-years generated for one mason+ two labourers**
Rural	7.85	7,000	55	11.55	109,148
Urban	3.34	23,000	77	16.17	152,807
Total			132	27.72	261,955

Source: Based on Housing Condition in India, (2004).

Every time a building is repaired or preventative maintenance is carried out, the materials and processes adopted generate income for the construction workers and also impacts on the environment. If high energy-intensive materials such as cement and steel are used in repair work, the impact will be more than the low energy materials such as stabilized mud block, etc. The emission of CO_2 is also dependent upon the type of materials adopted in the construction. Such impact, when considered on a regional or national level, may be very significant. Therefore, it may be useful to study the life cycle impacts of various maintenance actions of social infrastructure.

The life span of a building depends upon care and timely intervention by the users. Therefore, focusing on the cost and environmental aspects of social infrastructure construction only may not lead to sustainable development if the users are not taken into account in the process. Field experiences of Orissa and Andhra Pradesh reveal that there is a general lack of ownership of the Government-supplied social infrastructure since most of them are built with the help of contractors and hence, do not have any scope for community involvement. To increase the ownership of such buildings, the process of social infrastructure construction should keep the community in the centre, following DFID's Sustainable Livelihood Approach (DFID, 1997).

4.5. CONCLUSIONS

The above section demonstrated some of the impacts of construction technologies on socio-economy and environment at district level. The examples of primary healthcare buildings at Barikpur and Panasapada have shown the impacts on the three pillars of sustainability at grass root level. Therefore, in the light of Figure 4-4 and Figure 4-5, the parameters of impact assessment can be the unit cost, labour-intensity, income multiplier effect, embodied energy, CO_2 emission of the materials and technologies adopted in construction. Following the international guidelines for sustainable development discussed in chapter 2, the socio-economic and environmental impact assessment, as a national instrument, shall be developed for the decision makers. Therefore, the project level experiences are to be transformed into an assessment tool to enable sustainable social infrastructure development.

It has already been discussed in chapter 2 that the key issue in developing assessment tool is the availability and reliability of database. Ashworth (1993), Cole and Sterner (2000), etc., have emphasised that the lack of appropriate, relevant and reliable historical cost information and data are the major deterrent for adopting life cycle assessment. In this connection it may be noted that the database of DFID-funded Andhra Pradesh Primary Education Project has been well documented (1995-96). Under this project, primary school buildings using different technologies were constructed at 29 sites of Ranga Reddy district under the same degree of quality control. The buildings are in the same social, geo-climatological settings; therefore, they are ageing under uniform conditions. The physical conditions of these buildings were examined in 1998 and the corresponding interventions took place in 1999-2000 that was implemented with the help of the communities. The entire process and data of the new construction and repair programme have been documented, which has provided some idea on life cycle impacts of the various construction technologies used in Andhra Pradesh.

Before we embark on the development of an impact assessment tool, we shall examine the Andhra Pradesh Primary Education Project experience in the following two chapters. This will enable us to understand whether the Andhra Pradesh experience could be accepted as a basis for developing of an impact assessment tool. The detail of both process and product of the project have been described in these two chapters so that one understands the nature of database along with the context.

CHAPTER 5 ANDHRA PRADESH PRIMARY EDUCATION PROJECT

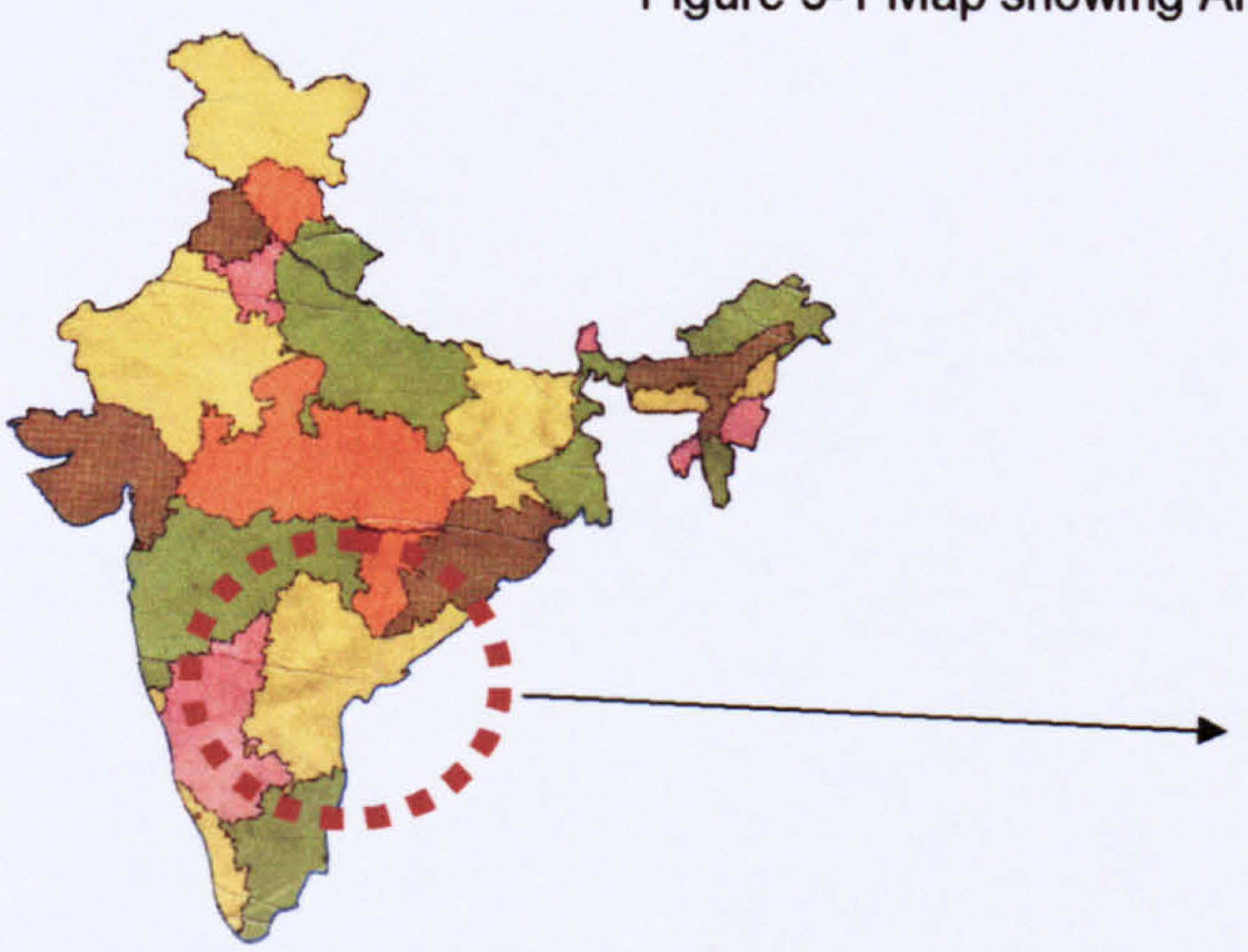
It may be recalled that the first objective of this dissertation is to describe the Andhra Pradesh Primary Education Project and examine its efficacy as a base for developing an impact assessment tool. In this chapter we shall examine this project to ascertain whether it has the merit to be the basis for the assessment tool.

In 1995-96, Overseas Development Administration (ODA) (presently DFID) funded programme was undertaken in Andhra Pradesh State of India to identify different options of construction technologies that are cost effective, low maintenance intensive, labour intensive and environment friendly. The process and product of the project in Andhra Pradesh will now be examined to know whether it can offer any clue towards sustainable social infrastructure development within the existing framework of the Government policies on cost, livelihood and environment protection in the social infrastructure sector.

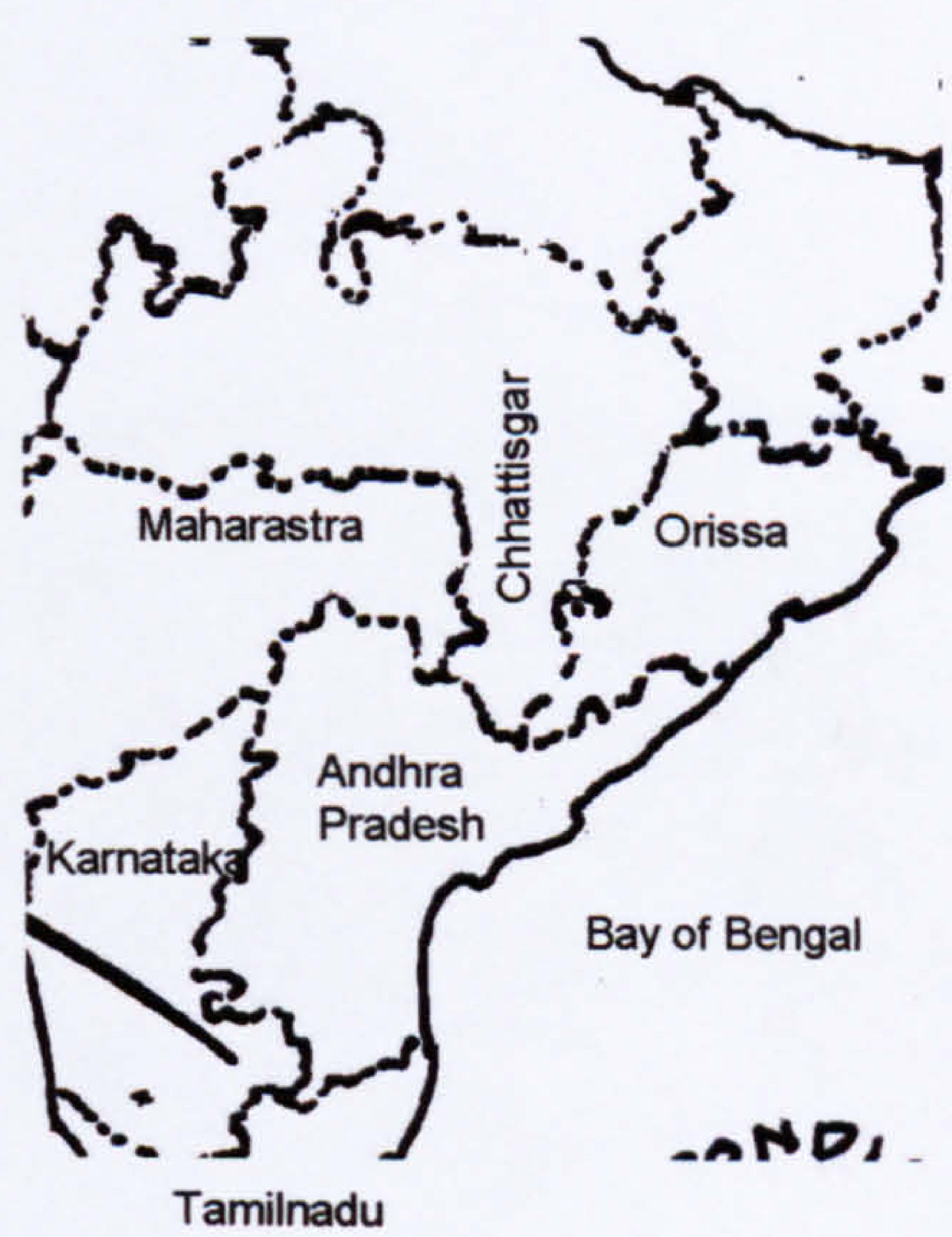
5.1 THE BACKGROUND

Andhra Pradesh, one of the Southern States of India, is bounded by Orissa, Chhattisgarh, Maharastra, Karnataka and Tamilnadu. The Bay of Bengal is on the eastern side of Andhra Pradesh.

Figure 5-1 Map showing Andhra Pradesh



Source: The TTK Atlas (1995), Chennai, India



A majority of the local people speaks the language called "Telugu". The state had and continues to have problems of providing adequate sheltered primary schools owing to financial shortage. In the early 1990s, the Ministry of Education, Government of Andhra Pradesh was implementing the Andhra Pradesh Primary Education Project with financial assistance from the British Government's Overseas Development Administration (ODA). Panchayati Raj Engineering Department was constructing the primary schools in Andhra Pradesh on behalf of the Department of Education. During implementation, it was realised that providing sheltered learning environment for every child eligible to attend school was a costly affair, and it was growing costlier every year. Therefore, Andhra Pradesh Primary Education Project (1993-1996) explored the possibility of producing primary school structures in a cost effective manner. The state Government, with technical support from the ODA, set about looking for cost effective approaches that could provide the infrastructure at a reduced capital expenditure.

Five possible ways were identified by which savings could be made:

- by using locally available materials and human resources;
- by eliminating redundant specifications;
- by optimising spans and shapes of the rooms;
- ensuring quality control and good management
- by implementing effective community participation.

However, in the pilot programme, it was not possible to involve the community directly in the process owing to the time constraint of the project. It was restricted to regular dialogue between the implementation team and the community.

5.2 THE PROCESS

BACKGROUND: ALTERNATIVE CONSTRUCTION TECHNOLOGIES

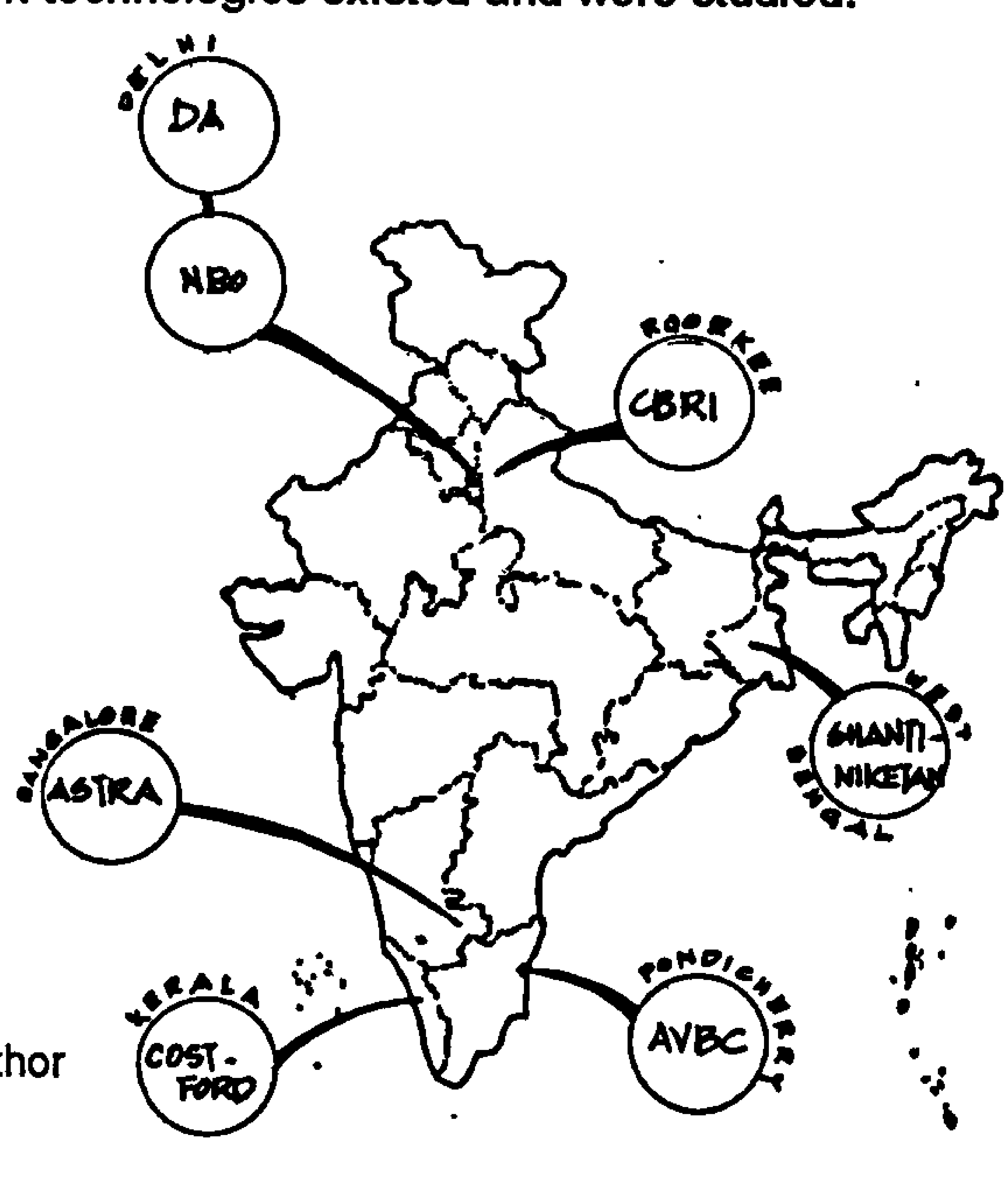
The policy makers at Government of Andhra Pradesh and DFID principally agreed that intensive technical support was necessary for capacity building of the engineers of the Panchayati Raj Engineering Department in the venture of cost effective construction technologies. It was decided that a series of prototype buildings using some of the cost-saving technologies will be constructed. The Panchayati Raj Engineering Department could then mainstream some of the technologies suitable for Andhra Pradesh, which in turn, would enable the Government towards sustainable development in the field of education infrastructure.

Technologies Identification Mission and Selection Of Agencies For Implementation Of The Cost Effective School Buildings

As described in chapter 1, a desktop research was carried out by the author on various agencies promoting cost effective construction technologies in India. This was followed by field visits to the different research institutions for data collection on construction technologies promoted by them. The data was analysed considering the unit cost of construction, durability, availability of materials and skill, energy consumption, income generation, acceptability and maintenance requirements. Based on the data analysis, construction technologies that were feasible in Ranga Reddy district were short-listed.

Figure 5-2 shows the major locations in India where institutes' and individuals' works on cost effective construction were studied in detail to select the appropriate ones for Andhra Pradesh. Based on the technologies identification mission, evaluation and desktop research, The Central Building Research Centre, the Centre of Science and Technology for Rural Development, the Development Alternatives in New Delhi, Design Architecture and Associated Technologies and PK-PEU DAS (author's consultancy firm) were short-listed for implementing the various cost effective construction technologies. Central Building Research Institute participated in the programme as a technical support and hence, the Panchayati Raj Engineering Department had to take the responsibility of constructing buildings using their technologies.

Figure 5-2 The map showing locations of the places where good examples of cost effective construction technologies existed and were studied.



Source: Author

SITE SELECTION AND RESOURCE MAPPING

Ranga Reddy district in Andhra Pradesh was selected for the demonstration of cost effective construction of school buildings. The Education Department identified twelve schools in the East and sixteen schools in the West of Ranga Reddy for the construction of cost effective demonstration buildings. The site selection was followed by Resource Mapping exercise conducted by the author of this dissertation to understand the suitability of various technologies in the district.

Based on the available materials, rat-trap bonded masonry wall, brick pyramids, corbelled brick arch roofs and filler slabs were chosen for Ranga Reddy East. Similarly, cement stabilised mud blocks, stone concrete blocks for walls and micro concrete tiles, ferrocement channel, reinforced concrete plank and joist and reinforced concrete channels and sandstone roofing were adopted (Appendix IV) in Ranga Reddy West. Another important aspect of selecting pre-cast systems was to encourage local entrepreneurship among the youths in the locality to generate more employment at local level. In general, local timber was used as door and window shutters. Minimum finishing was adopted in the demonstration school buildings since one of the objectives was cost reduction. The floors were made of Tandur (a district in Andhra Pradesh) unpolished stone of 40 mm thickness on 1:5:10 cement concrete.

APPROVAL OF THE ARCHITECTURAL AND STRUCTURAL DESIGNS AND ESTIMATIONS FROM THE PANCHAYATI RAJ ENGINEERING DEPARTMENT, GOVERNMENT OF ANDHRA PRADESH

The classroom designs were based on the state level standard of 40 students in a class and at the rate of 0.743 square metres per child. The appendix VIII shows the different types of designs that were approved. The approval of structural designs took a long time since the engineers were looking for published documents and books on systems such as corbelled pyramid. The basic rules of pyramid were derived from field studies and the research works by Bose (1932) and Ganguly (1912). Analysis of measured drawing of the existing temples led to a method of corbelling as shown in Appendix IV (section- IV.11). In consultation with the design engineer of the Panchayati Raj Engineering Department, a modified version of Terrington's (1957) method of analysis was used for approximate analysis of the corbelled pyramids.

Panchayati Raj Engineering Department followed a contract system based on Standard Schedule of Rates revised every year, which contained the approved materials and labour costs of various construction items. The Government had a fixed number of items for which the analysis of rates was approved. Many of the items under the present programme were not in the schedule. The Government engineers suggested that the items, which were not within the schedule, should be observed during construction so that an analysis of rates could be evolved.

Capacity Building

A five weeks' hands-on training programme on cost effective construction was conducted for the Panchayati Raj engineers in June-July 1995. The short-listed specialist agencies were involved in the training programme, so that the Panchayati Raj Engineering Department could learn the specific technologies and also build rapport with the agencies. The author supervised and also took part as resource person in the training programme.

Implementation

Immediately after the training, the Panchayati Raj engineers, in partnership with the specialist agencies, started construction. There was an initial delay since most of the agencies were from outside Andhra Pradesh. They were unsure of the co-operation from the political parties, Panchayati Raj Engineering Department and local villagers during implementation. The author of this dissertation started school construction at two villages named Majeedpur and Jaggamguda. Observing the progress at Majeedpur and Jaggamguda, the other agencies developed confidence and came down to Ranga Reddy with their supervising team to implement their designs. In September 1995 construction works at all the sites were in progress. By March 1996 most of the sites were in advanced stage as far as the cost effective items were concerned. By 31st March 1996 the final bills of most of the buildings were provisionally approved.

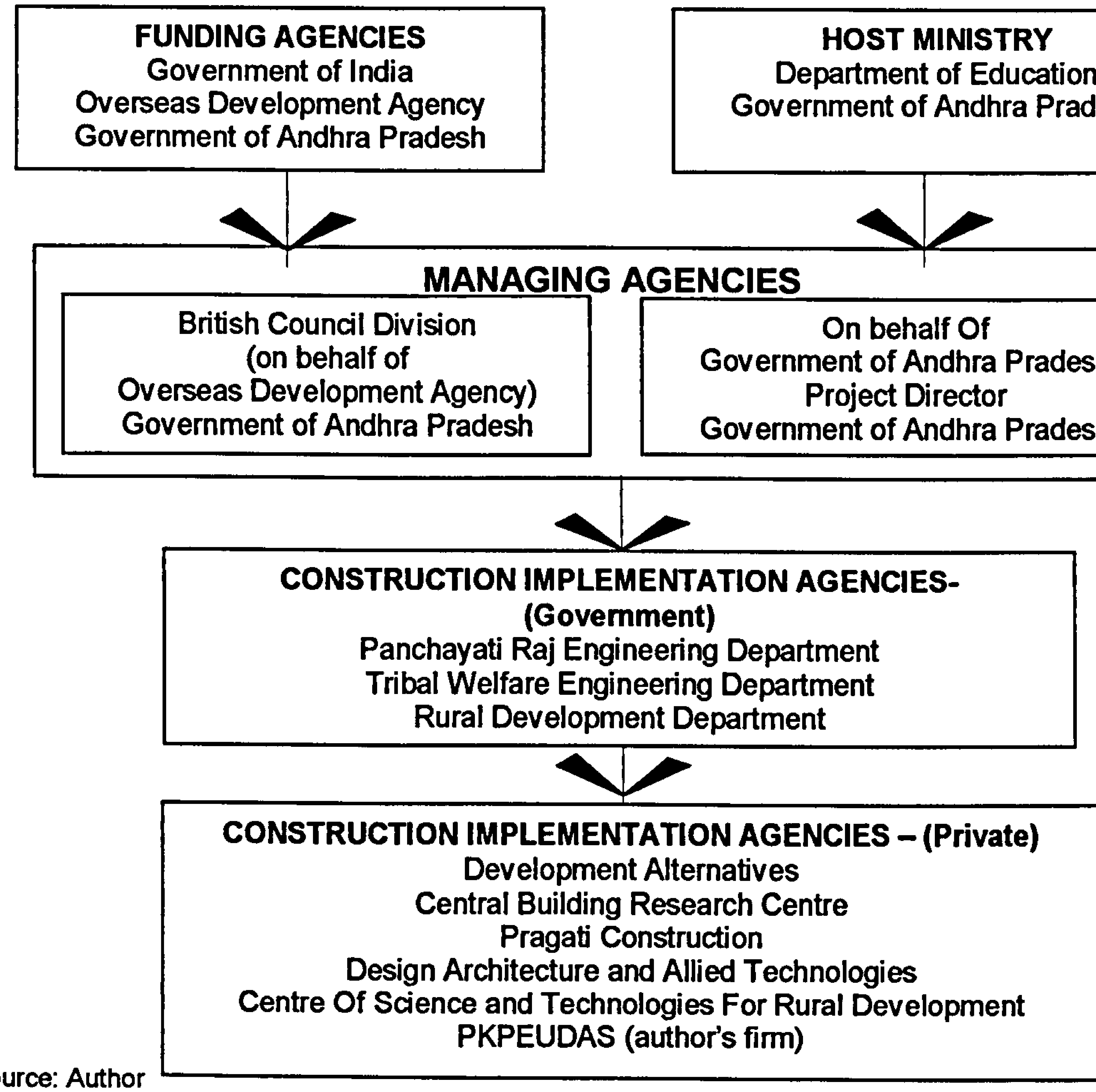
The Workshop

An international workshop was conducted at Hyderabad on 22nd - 24th November 1996 by DFID. The author of this dissertation documented the entire process of the workshop. A few international delegates from UK, representatives from most of the states of India and high level officials (Indian Administrative Service) participated in the workshop. It was coincidental that another centrally sponsored programme called the District Primary Education Programme had just been launched in more than 50% of the Indian states. The main objective of the programme was to achieve universal elementary education for all Indian citizens (DPEP, 1995).The demand for such social infrastructure was far too high compared to the existing stock and, therefore, the states under District Primary Education Programme took very special interest in the Workshop. Some representatives from the Orissa Health and Family Welfare Department came to see if some of the technologies could be adopted in the health sector.

Soon after the workshop, most of the states under the District Primary Education Programme adopted some of the technologies used in Ranga Reddy District (DFID, 1999). Figure 5-3 shows the organisation structure responsible for the entire process of the Andhra Pradesh Primary Education Project.

Figure 5-3 The organisation structure of the Andhra Pradesh Primary Education Project

ORGANISATION CHART OF ANDHRA PRADESH PRIMARY EDUCATION PROJECT



Source: Author

The above organisational structure had implemented prototype schools at twenty nine sites (constructed in 1995-96) using:

1. eleven different roofing systems
2. six different walling systems
3. one type of foundation system

The site level data collection process has been shown in detail in chapter 1. The database was published as a handbook for cost effective construction technologies for primary school construction. The following section is on the analysis of data collected from 29 school construction sites in Ranga Reddy district, Andhra Pradesh in 1995-96.

5.3 DATA ANALYSIS:

The process of data collection and the basic costs and embodied energy of the construction technologies used in demonstration school buildings have been presented in Appendix III and IV. All the unit rates are according to the standard schedule of rates (SSR, 1996) of the Government of Andhra Pradesh and observed data during the implementation.

NOTES ON DATA ANALYSIS

Chapter 1 shows that the data collection of Andhra Pradesh Primary Education Project was rigorous and systematic. This chapter will carry out a detailed analysis of the data on cost effective items adopted in Andhra Pradesh Primary Education Project to examine whether they could be used in other contexts with modifications according to the local conditions. Out of the twenty nine sites, sixteen have been considered for analysis since the remaining thirteen sites were based on the conventional steel and cement intensive systems. Out of the sixteen sites chosen for analysis, fifteen were based on alternative construction technologies and one was steel and cement-intensive (conventional). All the calculations are based on costs of materials, labour, etc., at Jaggamguda (Das, 1996). The analysis focuses on the socio-economic and environmental aspects of primary education infrastructure construction in Andhra Pradesh. It has been carried out in the light of international guidelines (discussed in chapter 2) and is broadly as follows.

- Pattern of variation in unit cost of construction of different construction technologies
- Degree of labour-intensity of various technologies, which is an indicator of livelihood generation of construction workers.
- Amount of money retained in the district, which is an indicator of local business opportunity generated. This is an indicator of income-multiplier also.
- Impact on environment of various construction technologies.

The types of technologies adopted in the school construction has been categorised into four groups. The first group had brick and/or cement -intensive wall with steel and cement-intensive roof. The construction technologies adopted in the villages named Kismatpur (conventional), Surangal, Chilkoor, Medipally, Chinnamangalaram and Sreeramnagar belong to this category.

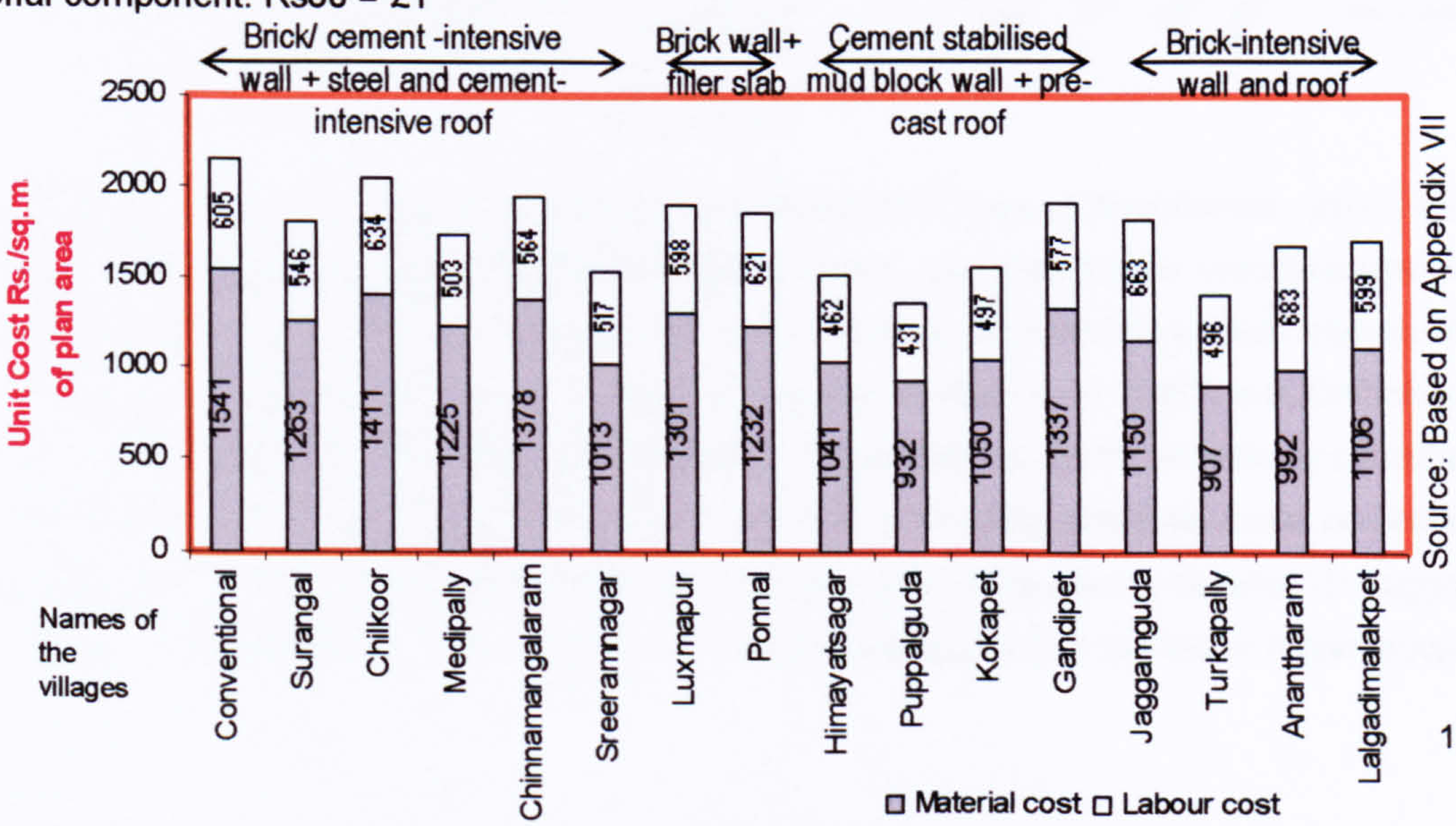
The second group had brick wall with filler slab (Luxmapur and Ponnal). The third group had cement stabilised mud block wall with pre-cast roof (Himayatsagar, Puppalguda, Kokapet and Gandipet). The fourth group had brick-intensive wall and roof (Jaggamguda, Turkapally, Anantharam and Lalgadimalakpet).

5.3.1 Pattern of Variation in Unit Cost of Different Construction Technologies

It may be noted that the process of data collection of the Andhra Pradesh Primary Education Project has been discussed in chapter 1. The focus of this chapter is on analysis of the data collected from sixteen villages in Ranga Reddy district. Therefore, the issues such as design, materials, human resources, etc., are village-specific. We shall now carry out a village-specific data analysis to examine whether it leads to the development of an impact assessment tool and whether a database could be generated for calculating the impacts of different construction technologies.

It may be recalled that, based on the resource mapping exercise carried out in Ranga Reddy, a number of feasible technologies were short listed for walling, roofing, openings, etc. As mentioned in chapter 1, detailed data collection was carried out during the construction work that was analysed and approved. Chapter 1 shows the process of site-specific analysis of data in Microsoft Excel File 2 hyperlinked with worksheets "A", "B", "C", "D and "G" (Figure 1.7). The following Figure 5-4 is the summary of the cost of construction using various technologies in Ranga Reddy District, which shows that the conventional school construction was the most expensive, whereas the least expensive one was at Puppalguda.

Figure 5-4: Unit cost of construction at different sites in Ranga Reddy district showing labour and material component. Rs80 = £1



It may be noted that the designs adopted at different sites were different as shown in Appendix VIII. The plinth heights at different sites, with respect to the near-by roads, were also different. Therefore, this chapter will analyse the village-specific impacts of different construction technologies, designs and ground levels on socio-economy and environment per unit plan area of the schools in Ranga Reddy. Figure 5-4 shows that there was a wide variation in cost per unit plan area owing to the use of different technologies in construction. The most labour-intensive building was at Anantharam. In many schools, verandas were provided along with classrooms. A Verandah is less expensive than the classroom and hence, the average unit cost of the construction in the designs with classroom and verandah was less than the ones with rooms only. One of the reasons for the high unit cost at Gandipet, Luxmapur, Chinnamangalaram, etc., may be attributed to the design aspects, i.e., these schools consisted of classrooms only. In contrast, Puppalguda having two rooms with verandah classrooms all around had low unit cost.

Figure 5-5 The percentage of labour and material at different sites in Ranga Reddy district

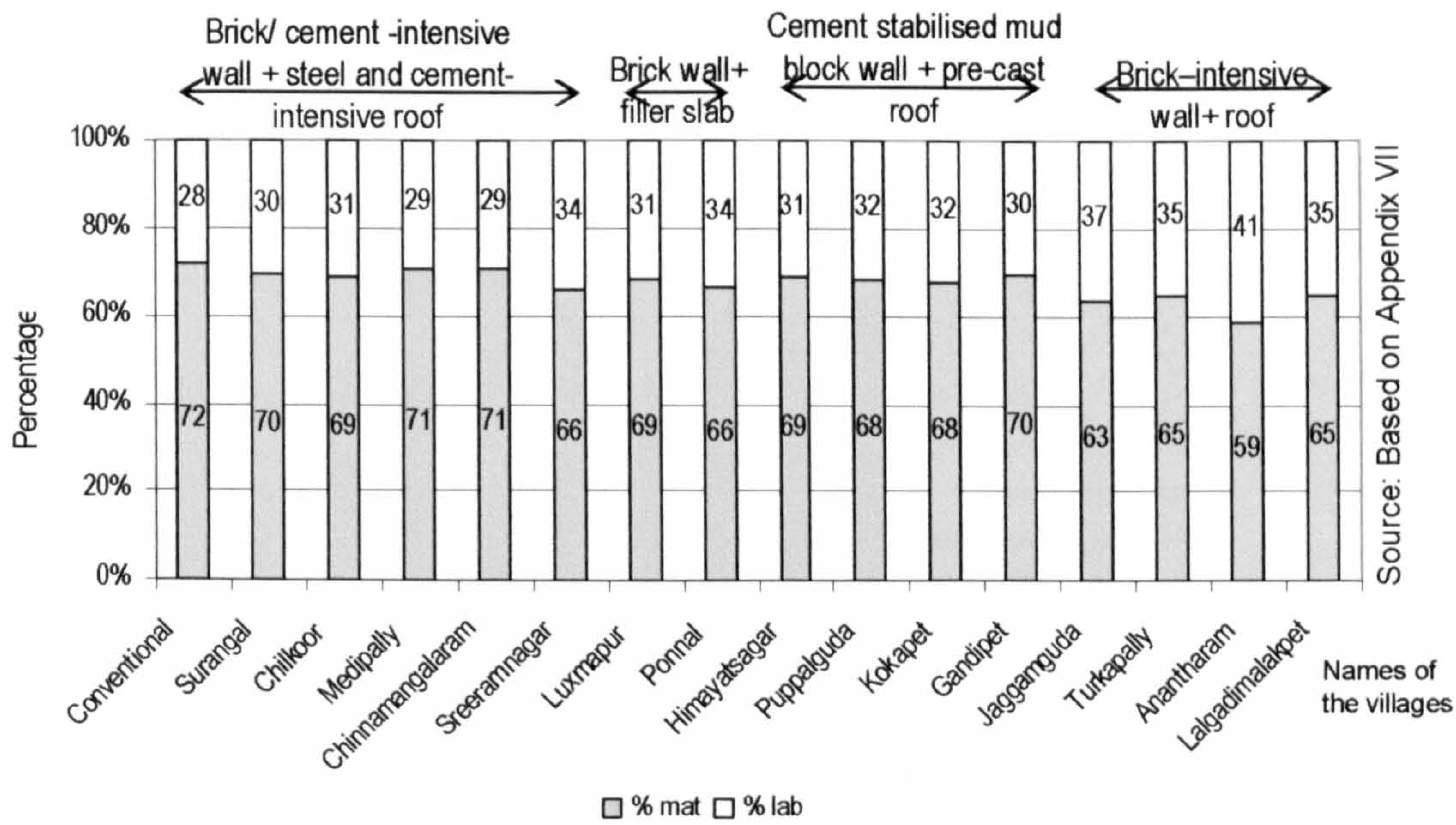


Figure 5-5 shows that the most labour intensive building (41%) was at Anantharam, which had a rat-trap bonded brick wall and a brick arch roof, whereas, the least labour intensive was with conventional technology. Figure 5-5 shows that the percentage of materials varied between 59% and 72%. It may be noted that, Olotuah (2002) (referring to Fadahunsi (1987) and Onibokun et al (1990)) states that the cost of building materials in the total expenditure on housing constitutes about 60% in Nigeria. According to Olotuah, if the cost of building materials could be reduced further, the low cost houses will be within the economic reach of the poor in Nigeria. He suggests the use of earth buildings for cost reduction. Therefore, it appears that the technologies adopted in Nigeria are less material-intensive than Andhra Pradesh. However, Olotuah does not describe the technologies adopted and cost break-up to supplement his statement. According to Tiwari (2001), building materials often constitute approximately 70% of the actual construction costs in developing countries, however, the material cost in Ranga Reddy varied between 59% -72% and the average was 67.6%.

At this point, it is necessary to examine the costs of the different components of a building, e.g., foundation, wall, openings, roof, doors, windows and finishing items. It may be noted that these components are, by and large, exclusive from each other. For example, one may go for a low cost walling and roofing systems but may use high cost finishing materials and doors and windows. Analysis by component will enable us to choose the most cost effective combination of foundation, wall, opening, roof, door windows and finishing items of a building in a particular context.

<u>**Analysis By Component**</u>

Figure 5-6: The unit costs of the building components (showing the maximum and minimum of each component). Rs80 = £1.

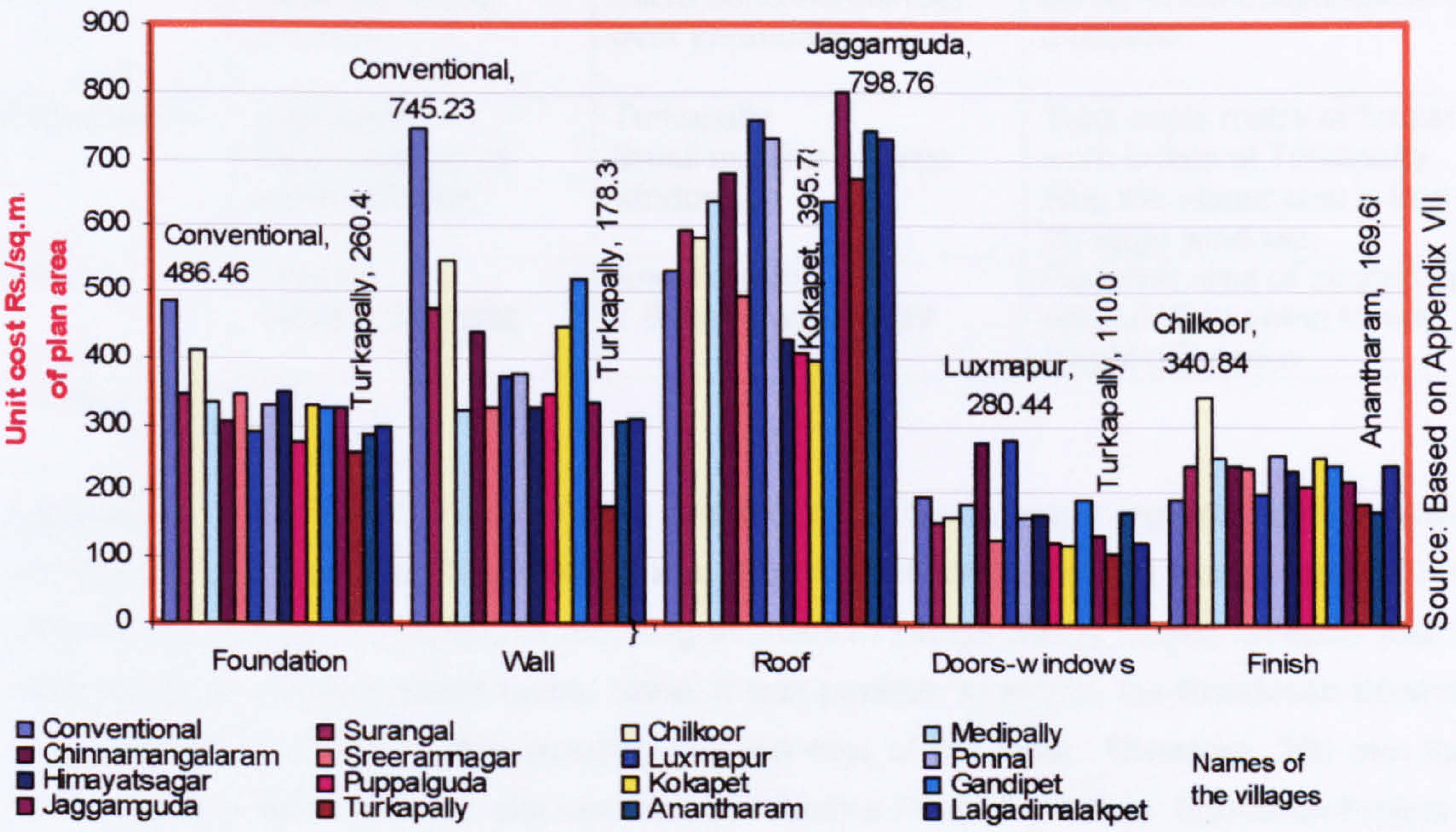


Figure 5-6 shows the pattern of unit cost of foundation, wall and roof, door/window and finishing items at sixteen villages in the Ranga Reddy district, which were based on different construction technologies. The above figure shows that the major contributors of a building cost are its roof, wall and foundation than the finish, doors and windows.

In the context of the search for low cost construction in Andhra Pradesh, DFID and Government of Andhra Pradesh decided that the investment on foundation, wall and the roof must be lower than the conventional technologies without violating the national norms and standards on structural safety and durability. The finishing items were kept to the minimum, e.g., rough stone flooring. The maximum and minimum unit costs of the five building-components were as follows.

Table 5.1 The maximum and minimum unit costs of the building components

Building-components	**Maximum Cost/ square metre**	**Minimum Cost/ square metre**	**Reasons for minimum cost**
Foundation	Conventional 450 mm thick random rubble masonry	Turkapally 380 mm thick coursed rubble masonry	Reduced foundation wall thickness
Wall	Conventional (3 metre wall height) 345 mm clamp bond brick masonry	Turkapally(2.1 metre wall height). 230 mm +115 mm kiln burnt brick masonry	Reduced wall thickness and wall height
Roof	Jaggamguda Brick pyramid in class room and verandah	Kokapet Jackarch in classroom + micro concrete tile roof over verandahs	Micro concrete tile roof is the cheapest roofing option owing to low consumption of materials.
Door window	Luxmapur Large number of small windows.	Turkapally Small number of large windows.	Total cubic metre of timber work is less at Turkapally. Also the labour cost is less for large windows.
Finish	Chilkoor 3 metre high wall	Anantharam 1.8 metre wall height	Reduced area of plastering and painting owing to wall height difference

Source: Author

Foundation: The conventional foundation adopted by the Government engineering departments and the villagers in Ranga Reddy district was 450mm thick random rubble stone masonry in 1:6 cement-sand mortar. The resource mapping exercise in Ranga Reddy district revealed that, by using locally available coursed rubble stone, it was possible to reduce the foundation thickness from 450 mm to 380 mm, thus reducing the unit cost of the latter. Therefore, 380 mm thick coursed rubble stone masonry was introduced in Andhra Pradesh Primary Education Project as an alternative to the conventional system. The first bar in Figure 5-6 shows that the conventional classroom design with 450 mm foundation was the most expensive option (Rs.487, i.e., £6.09 per square metre). While the rest of the bars showing foundation costs were of 380 mm foundation thickness, there was a variation in unit cost. This was primarily owing to the different plinth heights and plan-forms adopted at different villages. According to the Government of

Andhra Pradesh norms, the minimum plinth height should be 450 mm from the road level to protect the floor space from water logging in the rainy season. Since some of the sites were lower than the road level, higher plinth heights had to be provided, which increased the foundation costs. Apart from that, some designs were more expensive than the others owing to increased foundation length, e.g., at Chilkoor, two foundation walls close to each other (Appendix-VIII, Figure VIII.25) on either side of the corridor increased the cost of foundation (Rs.411, i.e., £5.14 per square metre). The least expensive foundation was at Turkapally (Rs.261, i.e., £3.26 per square metre) with 380 mm foundation thickness. Among the same foundation system, the difference between Turkapally and Chilkoor was 36%. The minimum unit cost of foundation at Turkapally could be attributed to the flat ground having the same level as the road and also its octagonal plan form, which reduced the foundation length. Therefore, apart from the construction technologies, the plan forms and ground levels were the two major factors that determined the foundation costs in Andhra Pradesh Primary Education Project.

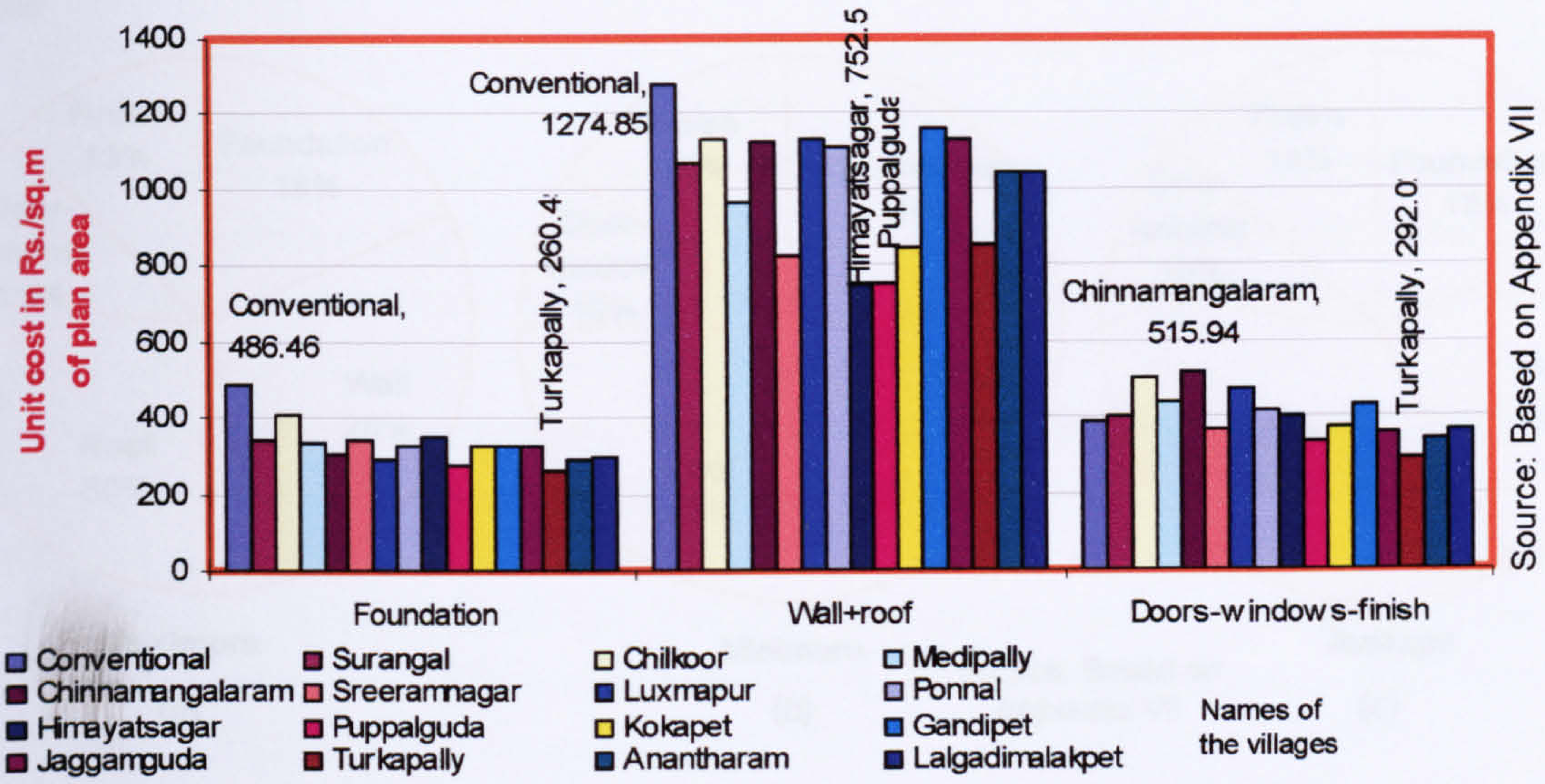
Wall: Figure 5-6 shows that the unit cost of walling systems had a wider variation than that of foundations. Turkapally had the least expensive walling system with a unit cost of Rs.178 (£2.23) per square metre, in which a combination of 230 mm and 115 mm thick brick masonry was used. The most expensive walling system was the 345 mm thick brick masonry wall (conventional technology) with a unit cost of Rs.745 (£9.31) per square metre. This huge difference could be attributed to a few factors. First of all the wall thickness of 345 mm in the conventional system consumed more cement, sand and bricks than the combined 230 mm and 115mm walling at Turkapally. Apart from that, the wall height at Turkapally was 2100 mm, compared to 3000 mm in the conventional walling system. It is important to note that the wall heights were determined by the roofing systems. All flat roofs required an average floor to ceiling height of 3000 mm according to the Government of Andhra Pradesh norm. Since conventional roof was flat reinforced cement concrete slab, the 345mm thick wall height had to be 3000 mm. However, Turkapally had a pyramid roof, which created a ceiling height of 4000 mm at the centre of the room and hence, the wall height could be reduced to 2100 mm to match with the requirement of average floor to ceiling height of 3000 mm. Because of this, the difference of 900 mm in wall height and smaller wall thickness made the unit cost of Turkapally much lower than that of the conventional system. Therefore, it appears that the unit costs of walls alone may be misleading since a low cost wall may carry an expensive roof. Hence, the unit costs of the combinations of different walling and roofing systems will be considered for comparing their cost effectiveness.

The first bar of the walling systems in Figure 5-6 was the conventional 345 mm clamp bond brick masonry and the rest of the bars were based on alternative systems. The second to the sixth bars (from left) representing walling systems in Figure 5-6 were of stone concrete block masonry in 1:6 cement-sand mortar. The wide variation of unit costs within the same walling technology is owing to the plan-form and roofing type, e.g. the unit cost of wall at Chilkoor (the third bar) is the highest in this group owing to the wall height (3 metres) and length (explained in foundation). At Medipally (fourth bar), one covered classroom and two verandah classrooms with roof supported by masonry pillars (Appendix VIII, Figure VIII.27) is the main reason for low unit cost of wall. Similarly, the variation in unit wall cost within the cement stabilised mud block, interlocking cement stabilised mud block and rat-trap bonded walls shown in Figure 5-6 were either because of different wall height or wall length depending upon roof type and/or plan form.

Roof: As with the wall, there was a considerable variation in unit costs of different roofing systems used in the project. The roof at Kokapet (Rs.396, i.e., £4.95 per square metre) was the least expensive and the most expensive one was at Jaggamguda (Rs.799, i.e., £10 per square metre). The school buildings at Kokapet had jack arch-roof over the classroom and micro concrete tile roofing on the two verandas (Appendix VIII, Figure VIII.22). It may be noted that micro concrete tile was the cheapest of all the roofing systems used in the Andhra Pradesh Primary Education Project. Therefore, using this in the verandas had helped in reducing the overall roofing cost at Kokapet. Jaggamguda had corbelled brick pyramid and stone cover slab in the verandah and the classroom and hence, the roof cost was high. It may be noted that the corbelled roofs were more expensive than jack-arch roofing (Appendix IV). It is important to note that the conventional reinforced cement concrete roof is the fifth lowest in terms of unit cost (Figure 5-6). However, the conventional foundation and wall were the most expensive options. Figure 5-6 shows that the unit costs of the roofs at Lalgadimalakpet, Turkapally and Jaggamguda are much higher than that of Himayatsagar, Puppalguda and Kokapet. However, wall costs of the former are low and hence, their combined roof and wall costs will provide a realistic picture on unit costs of the technologies.

It is, therefore, evident that the roof and wall cannot be treated in isolation since the wall heights are determined by the type of roofing system adopted. A walling system may be expensive but when used with sloping roof, low wall height will reduce the overall cost. Therefore, the combination of wall and roof will provide a more realistic picture on unit cost of construction of different technologies. Figure 5-6 has been recast in the Figure 5-7 by combining the unit cost of wall and roof in one group and doors, windows and finishes in another group.

Figure 5-7 : The unit costs of building components (combined in three groups) at different sites in Ranga Reddy district (showing the maximum and minimum of each component). Rs80 = £1.

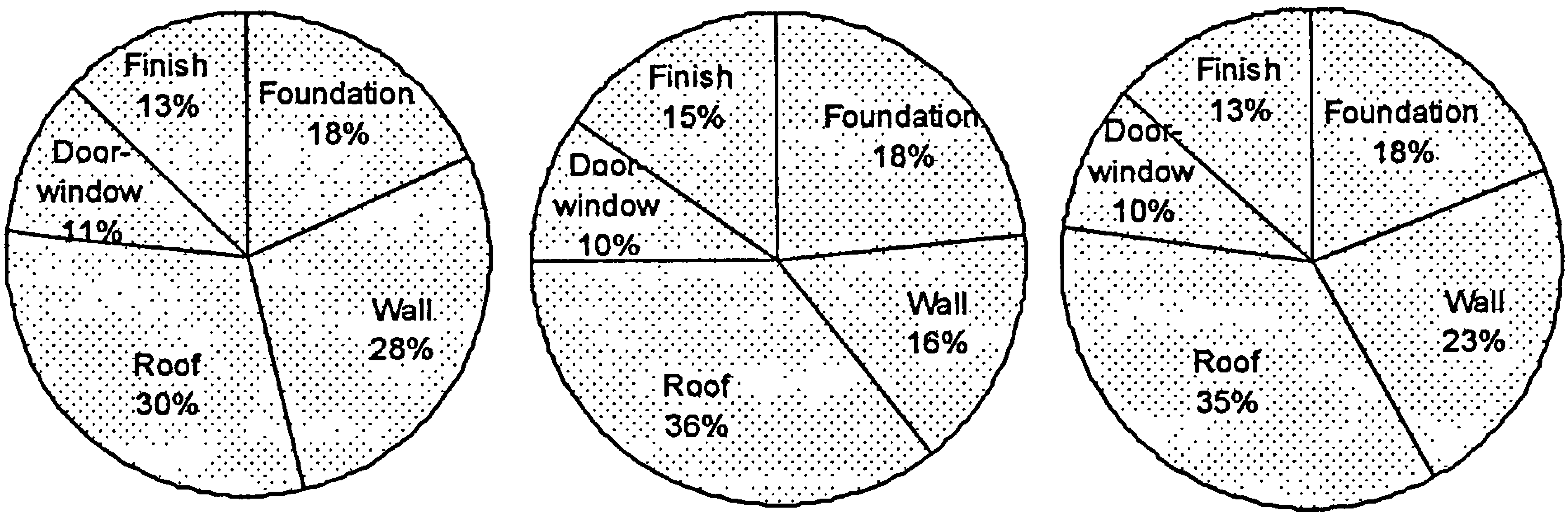


The overall pattern in Figure 5-7 shows that the conventional technology was the most expensive combination of wall and roof. The schools constructed at villages named Himayatsagar and Puppalguda were the least expensive. The combined wall and roof costs at Puppalguda and Himayatsagar were the lowest since the designs had classrooms with open verandah. The verandas had micro concrete tile and burnt clay tile roofing respectively, which were of low unit cost. Figure 5-6 shows that Anantharam (1800 mm wall height) had a slightly more expensive roof than Lalgadimalakpet (2100 mm wall height), however, its low wall height had reduced the overall cost and made it the same as the latter.

The bars representing combined cost of doors, windows (made of local timber) and stone floor finish show that the most expensive options out of the sixteen sites were at Chikoor and Chinnamangalaram owing to primarily the wall height of 3000 mm and also designs consisted of covered class rooms. Similarly low wall height (Turkapally), open verandas, etc., reduced the combined cost of doors, windows and finish.

Let us now look at the internal distribution of unit cost of a building by component, i.e., foundation, wall, roof, door, window and finish. In order to compare the degree of variation of the unit costs of the different components of a building, the average, the minimum and the maximum unit total cost, out of the sixteen sites, have been considered based on analysis of costs of in Ranga Reddy.

Figure 5-8: The distribution of total cost of construction on building components in rural primary schools at Ranga Reddy district. The maximum, minimum and average are based on the sixteen sites



Maximum (a) | Minimum (b) | Average (c)

Source: Based on Appendix VII

The pie charts (Figure 5-8) show that the unit cost of roof ranged from 30% to 36% (6% variation). There was also a wide difference of 12% in wall cost (range 16%-28%). The foundation and finishing items did not have much variation. The minor variation in door and window cost is owing to different numbers of them used in different designs. The major contributors of total building cost are foundation, wall and roof.

SOME OF THE IMPORTANT OBSERVATIONS ON UNIT COST OF CONSTRUCTION

The foundation, wall and roof consumed the major part of investment on the school buildings, i.e., 76% (average) of the total cost of construction. The wall plus roof combined formed about 58% (average) of the total cost. There was a wide variation of unit cost owing to the use of different technologies, designs and site conditions. The overall cost implications could be better understood as a combination of foundation, walling and roofing technologies rather than their individual component costs.

5.3.2 Degree of Labour Intensity of Various Technologies - an Indicator of Livelihood Generation of Construction Workers

UNIT LABOUR COST OF CONSTRUCTION

Some technologies were more labour intensive than others and hence, created more employment opportunities for the construction workers. Figure 5-5 shows that the percentage of labour cost varied between 28% for the conventional technology and 41% at Anantharam, where rat-trap bonded brick masonry wall and corbelled brick arch roofing were adopted. This difference of 13% is very significant and worth considering before recommending architectural design and technologies for a region. For example, if the technologies used at Anantharam were adopted (instead of the conventional technologies) in a project value of 100 million rupees (£1.25 million), an additional 13 million rupees (£0.16 million) worth employment opportunity could be generated. Considering the prevailing labour charges in Andhra Pradesh in 1995-96, which was Rs.71.5 (£0.9) per day for the skilled masons and Rs.37.8 (£0.47) per day for the unskilled workers and assuming that a team of two masons and four unskilled workers will work at a school construction site, an additional 44,188 working days could be generated. Figure 5-5 shows that conventional system was the least labour intensive (28%). Surangal, Medipally, Chilkoor and Chinnamangalaram had adopted stone concrete block masonry and pre-cast reinforced concrete roofing systems. They were of low labour intensity as shown in Figure 5-5. The brick intensive technologies such as rat-trap bonded brick masonry and brick pyramids showed a higher labour intensity, e.g., Turkapally 35%, Anantharam 41%, etc.

PATTERN OF SKILLS NEEDED FOR DIFFERENT TECHNOLOGIES

Figure 5-9 Unit cost of labour at different sites in Ranga Reddy district. Rs80 = £1.

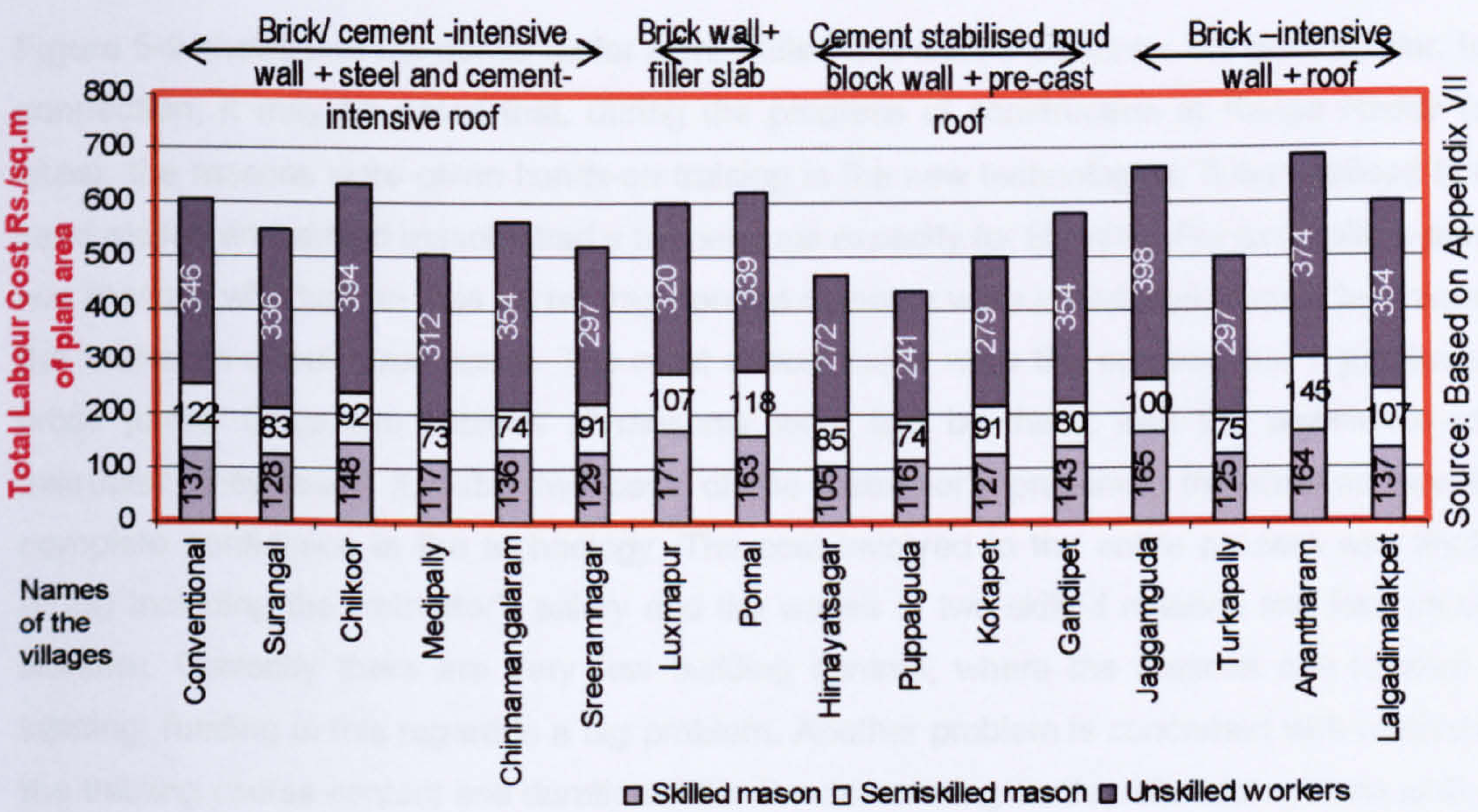


Figure 5-9 shows the labour cost per unit area at different villages of Ranga Reddy district, Andhra Pradesh. It also shows that the internal distribution of skilled, semi-skilled and unskilled workers' costs. The pattern of the graph indicates that the unskilled labour component of all the technologies is higher than the skilled and semi-skilled labour components. Currently, most of the agriculture labourers work in the rural construction sector during the non-harvesting seasons. It has been observed in Andhra Pradesh that most of the rural construction projects virtually stop during the harvesting seasons, thus posing a great problem in terms of price escalation and prolonged project period. Therefore, by promoting technologies with high percentage of un-skilled labour forces, there will be an increase in employment opportunities for the rural poor; however, the construction schedule should be designed after considering the harvesting seasons. Having said that the unskilled-worker-intensive construction technologies is supportive to the rural livelihood, it is important to note that this may be a deterrent for fast and very high quality building construction adopting sophisticated technologies. At present, the ratio of skilled masons to unskilled workers in most of the sites is more than 1:2 (Figure 5-9). By conducting training programmes for the semi-skilled workers they can be transformed from a low level to a high level of skill, which will increase their earnings. This has other advantage also, e.g., Price (1992) has demonstrated that there is a strong relation between level of remuneration and site productivity. In addition, the improved skill will lead to additional savings by reducing the wastage of materials during construction (Enshassi, 1996). All these may have an important bearing on the supply of the agricultural labourers and hence, there is a need for separate research in this regard, especially in the light of mechanisation in the process of agriculture.

Figure 5-9 shows that the demands for semi-skilled and skilled labourers are quite similar. In this connection, it may be noted that, during the progress of construction at Ranga Reddy (at all sites), the masons were given hands-on training in the new technologies. It was noticed that the semi-skilled and skilled masons had a tremendous capacity for learning. For example, a group of two masons who had no idea on rat-trap bonded masonry were introduced to such techniques by the trainer in about three hours. The most critical areas were the corners, the T junctions and cross joints. Once two courses of masonry were laid by them, with the assistance of the instructor, they learnt it. After two days of the instructor's presence, the masons developed complete confidence in the technology. The cost involved in the entire process was Rs.2,000 (£ 25) including the instructor's salary and the wages of two skilled masons and four un-skilled workers. Currently there are very few building centres, where the masons can receive their training; funding in this regard is a big problem. Another problem is concerned with uniformity of the training course content and duration. After the devastating earthquake and cyclone at Gujarat (2001) and Orissa (1999), the Ministry of Home Affairs initiated a mission for setting up a standard training module for construction workers in association with Indira Gandhi National Open University. The author of this dissertation, a national consultant to the Ministry of Home Affairs (India) for evolving masons' training, has been developing a certification process similar to that of the National Vocational Qualifications Authority in UK.

Let us now look again at the labour cost per unit plan area. By adding the stacks of Figure 5-9 it is found that the highest labour cost per unit plan area was at Anantharam (Rs.683, i.e., £8.54 per square metre) and the lowest at Puppalguda (Rs.431, i.e., £5.39 per square metre). Since the difference is very significant, it is highly important to study this aspect of infrastructure construction at the planning stage. However, one should not recommend a technology because of its high labour intensity only; one has to consider the overall unit cost of construction.

Let us now examine the labour cost per building component which will give us an idea on the distribution of labour costs in foundation, wall, roof, doors and windows and finish. The following pages describe the pattern of skilled, semi-skilled and unskilled workers by components of the buildings.

Figure 5-10 Cost of skilled masons per building component at different sites in Ranga Reddy District (showing maximum and minimum of each component). Rs80 = £1.

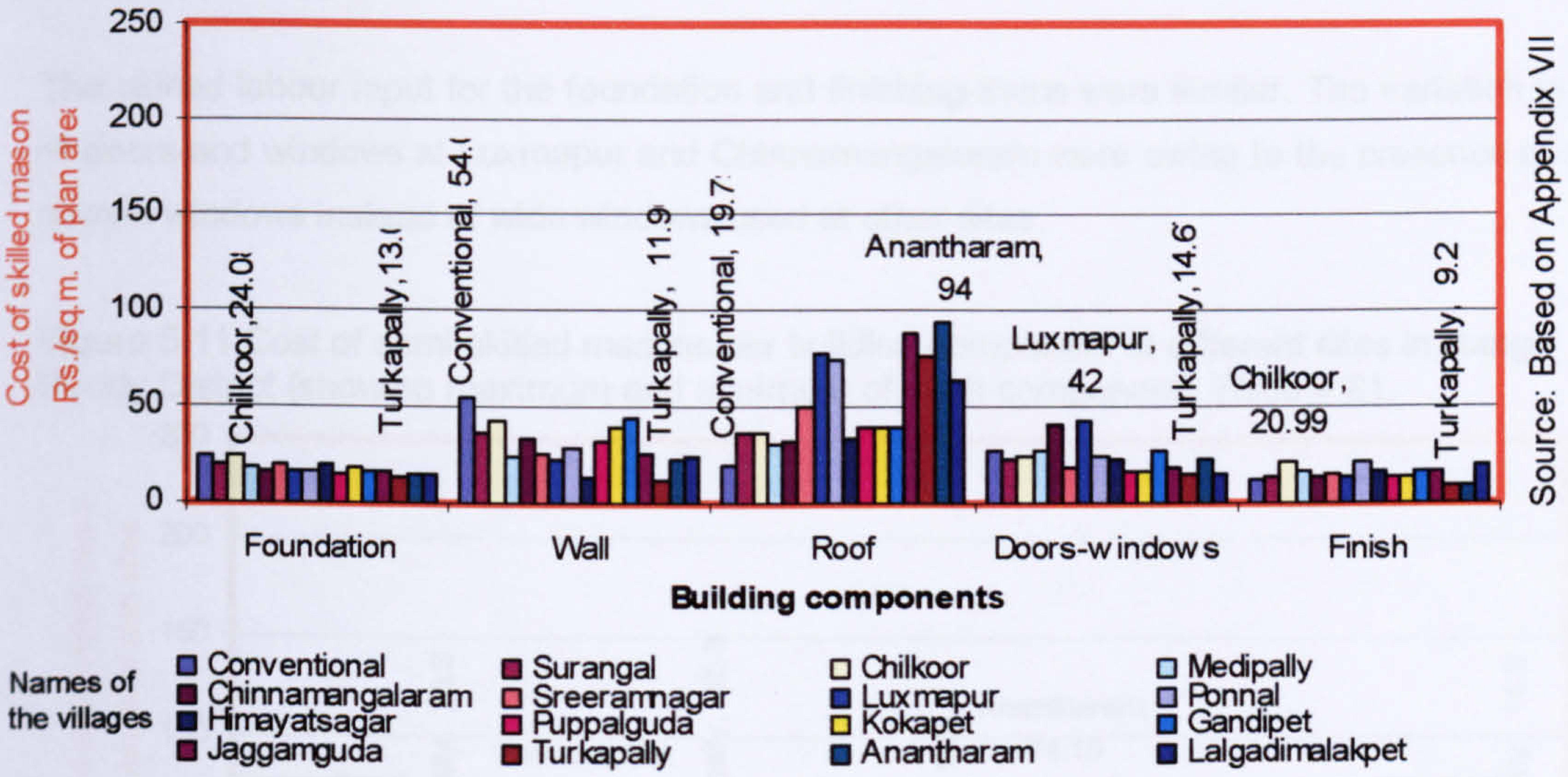


Figure 5-10 shows the overall picture of skilled labour requirements of different components of school buildings based on different technologies. The first bar under each component is conventional design and technology. The figure shows that the foundation requires low level of skilled workers whereas most of the roofs, walls and doors and windows require higher skilled labour component.

Each of the foundation, wall, roof, doors, windows and finish technology has a particular skilled labour requirement per unit area. However, the factors like architectural design, site conditions, wall height, wall thickness, etc., contribute to the overall skilled labour cost of different components of a building. For example, the conventional solid brick masonry had the highest skilled labour component (Rs.54, i.e., £0.68 per square metre), owing to its thickness of 345 mm, which was more than the other walling options, varying between 150 mm and 230 mm. The skilled labour component of wall in Figure 5-10 is low at Himayatsagar and Turkapally for two different reasons. The consumption of materials was low in Turkapally owing to a wall height of 2100 mm compared to the other systems having height of 3000 mm. In Himayatsagar, the use of 150 mm thick wall compared to the other options, varying between 190 mm and 345 mm, made it less skilled-mason intensive.

The corbelled brick arch roof at Anantharam was the most skilled-labour intensive system (Rs.94, i.e., £1.18 per square metre). The least skilled-labour intensive roofing system was reinforced cement concrete slab (Rs.20, i.e., £0.25 per square metre). The Figure 5-10 shows that the corbelled brick-intensive systems and filler roofs required a high skilled-labour component, whereas, systems based on pre-cast reinforced cement concrete joists had low skilled-labour input.

The skilled labour input for the foundation and finishing items were similar. The variation in case of doors and windows at Luxmapur and Chinnamangalaram were owing to the presence of many narrow windows instead of wide windows used at other sites.

Figure 5-11 Cost of semi-skilled masons per building component at different sites in Ranga Reddy District (showing maximum and minimum of each component). Rs80 = £1.

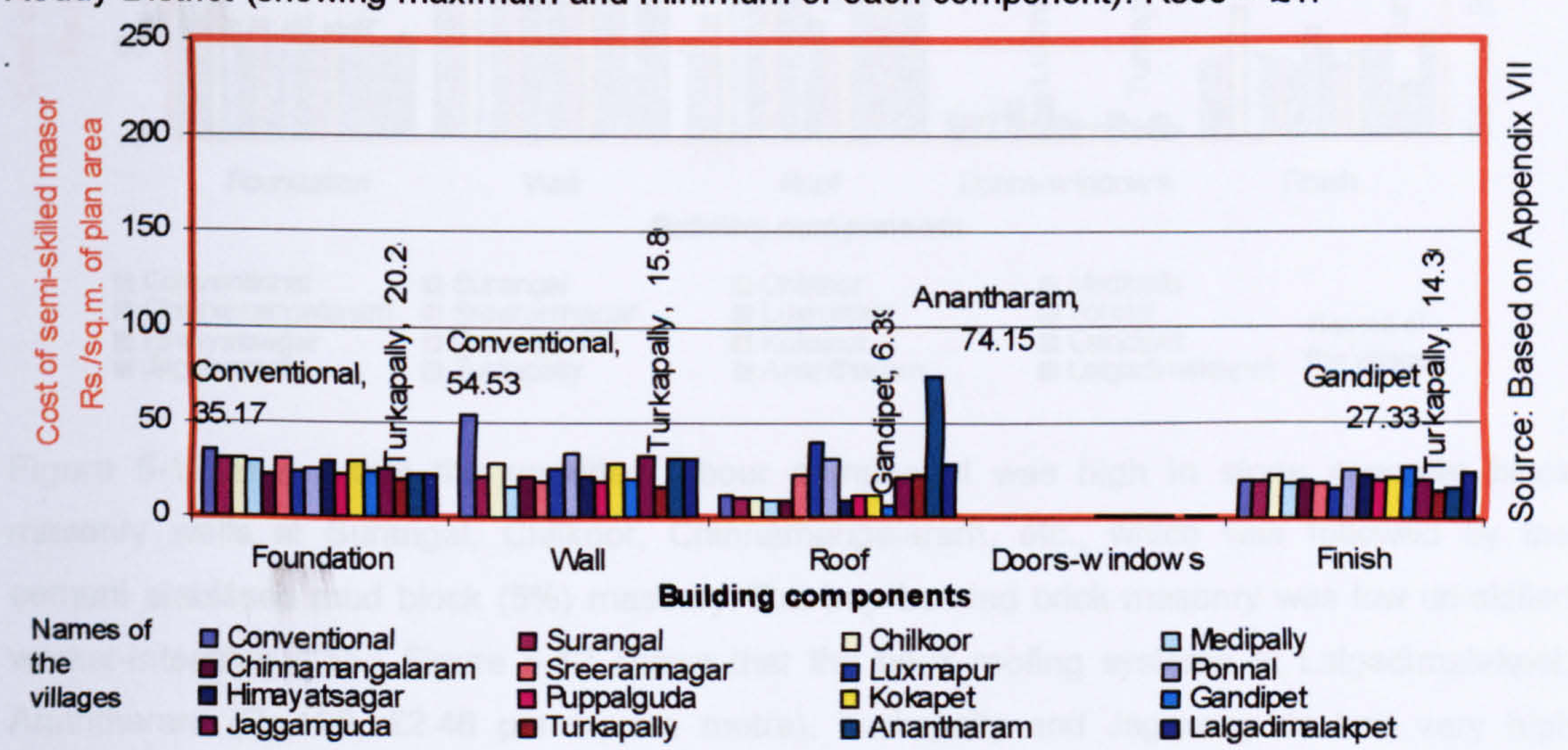


Figure 5-11 shows that the semi-skilled labour component of the 345 mm thick solid brick masonry was the highest. This labour component of the rat-trap bonded brick masonry wall at Lalgadimalakpet, Anatharam and Jaggamguda was also high. The semi-skilled labour intensity of the stone concrete block masonry (Rs.28, i.e., £0.35 per square metre at Chilkoor) was lower than rat-trap and higher than that of cement stabilised mud block (Rs.20, i.e., £0.25 per square metre at Gandipet). The variations among the same walling systems were owing to the architectural design, especially the combination of a classroom and two semi-open verandas.

The corbelled brick arch roof at Anantharam was the most semi-skilled labour intensive system and could be an opportunity for transforming semi-skilled masons to skilled ones. It is important to mention that the skill level of this category of masons involved at Anantharam improved significantly after they built the corbelled arch roof over four classrooms. The filler slab roof at Ponnal, Luxmapur, etc., also had considerable semi-skilled labour component, which is evident from the Figure 5-11. While the semi-skilled labour component of the foundations and finishes were comparable with that of the wall and roof systems, it was virtually non existent in doors and windows.

Figure 5-12 Cost of unskilled workers per building component at different sites in Ranga Reddy District (showing the maximum and minimum of each component). Rs80 = £1.

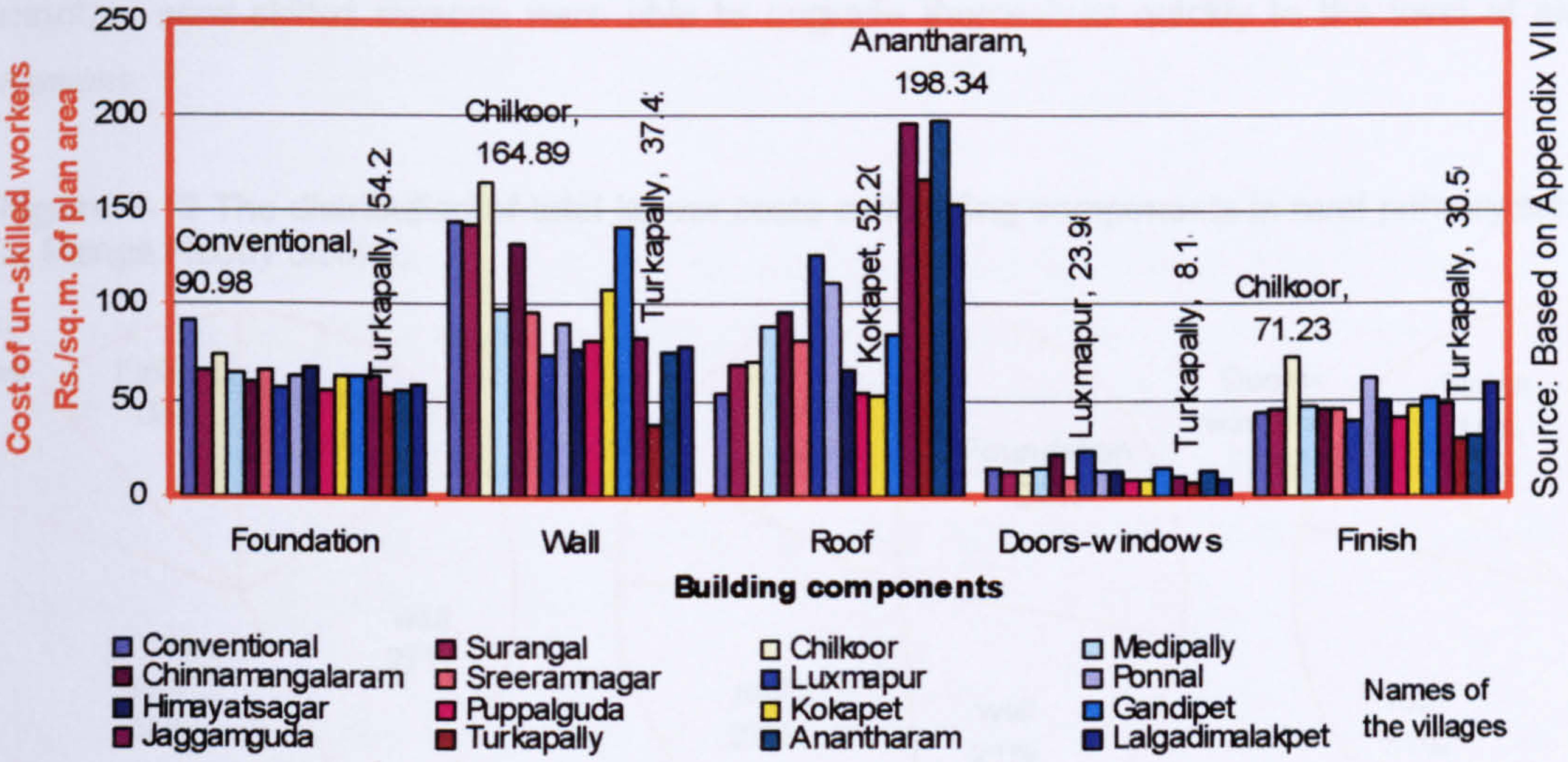


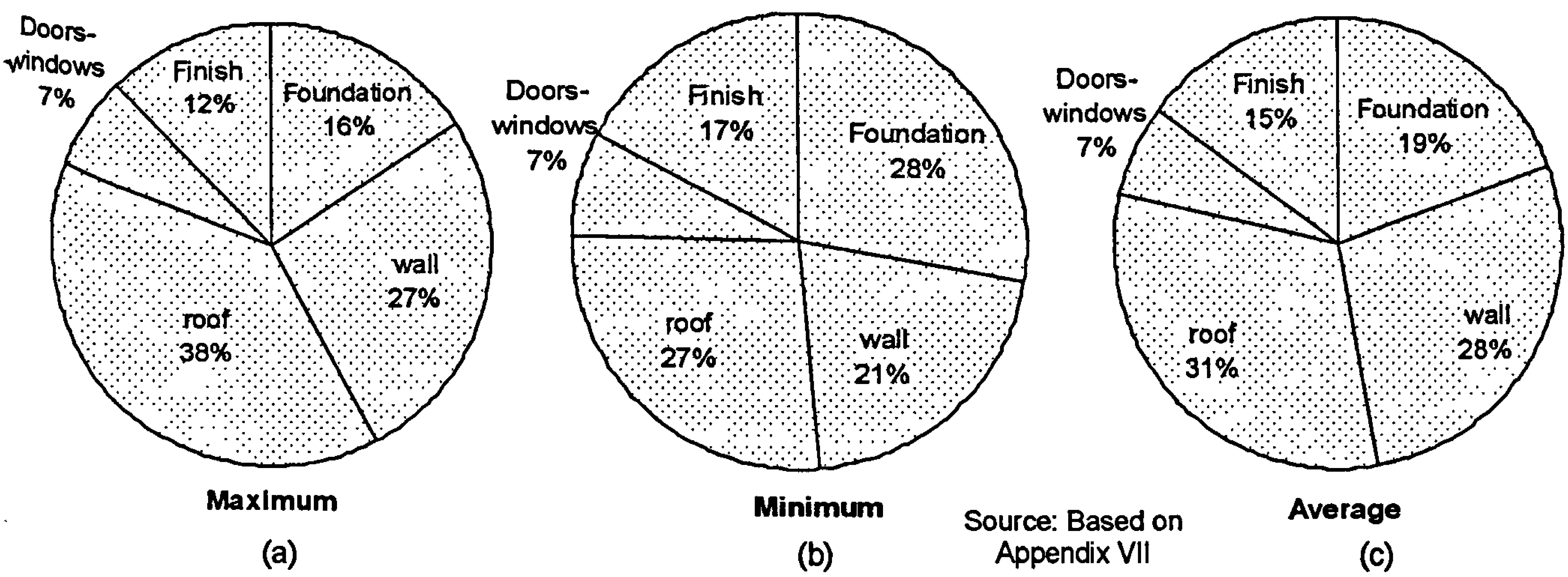
Figure 5-12 shows that the unskilled labour component was high in stone concrete block masonry walls at Surangal, Chilkoor, Chinnamangalaram, etc., which was followed by the cement stabilised mud block (5%) masonry. Rat trap bonded brick masonry was low un-skilled worker-intensive. The Figure 5-12 shows that the brick roofing systems at Lalgadimalakpet, Anantharam (Rs.198, £2.48 per square metre), Turkapally and Jaggamguda had very high unskilled workers' component. In comparison, the jack-arch roofing at Kokapet and Puppalguda (RS. 52, i.e., £0.65 and Rs.54, i.e., £0.68 per square metre) was very low in this regard.

Figure 5-12 shows that the general pattern of unskilled workers' involvement in foundations was higher than the skilled masons (Figure 5-10) and semi-skilled masons (Figure 5-11). The unskilled workers' cost in the finish was also higher than the skilled and semi-skilled components. This may be owing to use of stone flooring which is simple to construct and does not require much of skilled masons. The unskilled workers' component in doors and windows was lower than the skilled labour (Figure 5-10) since carpentry is a skill-intensive job.

SOME OF THE IMPORTANT OBSERVATIONS ON LABOUR COST

Figure 5-5 shows that the percentages of labour cost varied between 28% for the conventional technology and 41% at Anantharam, with a total difference of 13%. This type of data will enable the decision makers to understand the importance of choosing a particular construction technology over the others. The Figure 5-10 to Figure 5-12 show that the unskilled labour requirement is higher than the skilled and semi-skilled and hence, employment opportunity for the agricultural labourers in the off seasons is high. At present, wherever possible, the use of technologies with high intensity of semi-skilled mason may be encouraged. The Ranga Reddy district experience reveals that, given a continuous employment opportunity for a couple of months, semi-skilled masons were able to upgrade themselves quickly to the level of skilled masons.

Figure 5-13 The distribution of total labour costs on building components in rural primary schools in Ranga Reddy district.

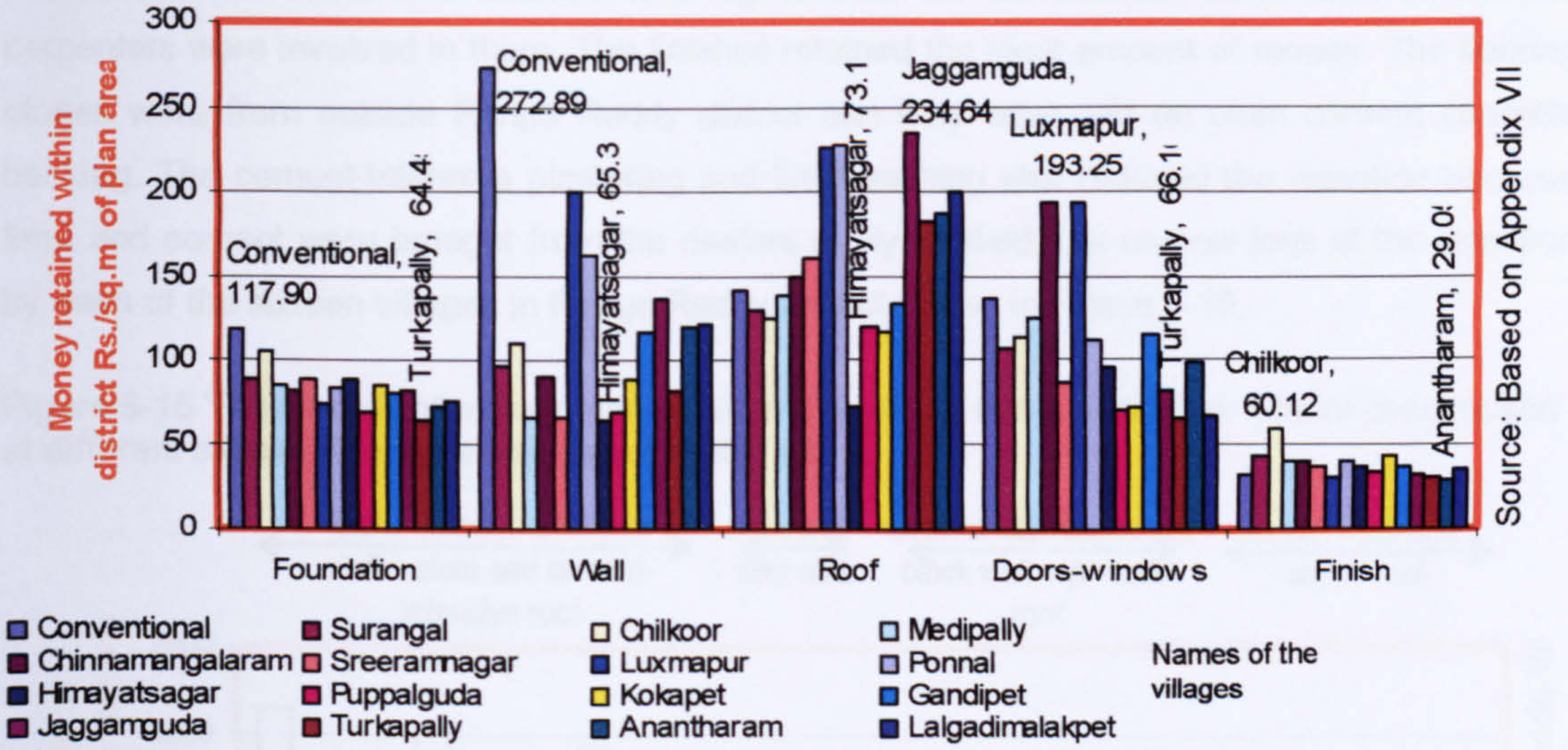


Source: Based on Appendix VII

The pie charts in Figure 5-13 show the maximum, minimum and average distribution of total labour costs per building component. The major portion of the labour cost is on the foundation, wall, and roof, which constitute a maximum of 81%, minimum 76% and an average of 78% of the total labour cost. Pie charts shown in Figure 5-13 are based on the data from sixteen sites in Ranga Reddy district.

5.3.3 Money Retained within the District - an indicator of Local Level Employment-Opportunities - also an Indicator of Income-Multiplier

Figure 5-14 The amount of money retained within Ranga Reddy district per building component at different sites (showing the maximum and minimum of each component). Rs80 = £1.



The net amount of local material cost, after deducting the cost of fuels, etc., brought from outside the district and the production labour, is the retention amount. For materials brought from outside the district boundary, only the agency charges have been adopted as retention. Table II.2 in Appendix II shows the retention of all the materials. The calculation of retention by different items in construction such as wall, roof, plastering flooring, etc., have been shown in Appendix III, Appendix IV and Appendix XVI. The Appendix VII calculates the site-specific impacts based on the Appendices III, IV and XVI.

Figure 5-14 shows that the retention of money by the conventional systems in foundations and walls were higher than the rest of the technologies, which may be attributed to the use of local materials such as coursed rubble stone and bricks. Apart from that, the wall thicknesses in the conventional system of foundation and superstructure wall were 450 mm and 345 mm compared to the other alternative systems, which were 380 mm and a maximum of 230 mm respectively. The additional investment on the conventional system owing to the greater thickness, made it expensive, which is also shown in Figure 5-6. Therefore, while the conventional system of foundation and wall retained more money within the district than the rest of the systems, they were expensive as well. The wall of Himayatsagar had the least amount of retention, which was owing to the use of cement intensive interlocking stabilised mud block masonry (150 mm thick).

The filler slab roofs at Luxmapur and Ponnal and the brick intensive roofs at Jaggamguda (Rs.234, i.e., £2.93 per square metre), Lalgadimalakpet, Anatharam and Turkapally had high retention as shown in Figure 5-14. The least retention was at Himayatsagar (Rs.73, i.e., £0.91 per square metre) since the ferrocement roof was a cement and steel-intensive system. The retention in the doors and windows was higher than the foundations, since local timber and carpenters were involved in them. The finishes retained the least amount of money. The flooring stones were from outside Ranga Reddy district and they were laid on plain cement concrete backing. The cement-intensive plastering and lime washing also reduced the retention because lime and cement were brought from the dealers at Hyderabad. Let us now look at the retention by each of the sixteen villages in Ranga Reddy district shown in Figure 5-15.

Figure 5-15 The amount of money retained in and went out of the district for school construction at different sites in Ranga Reddy district. Rs80 = £1.

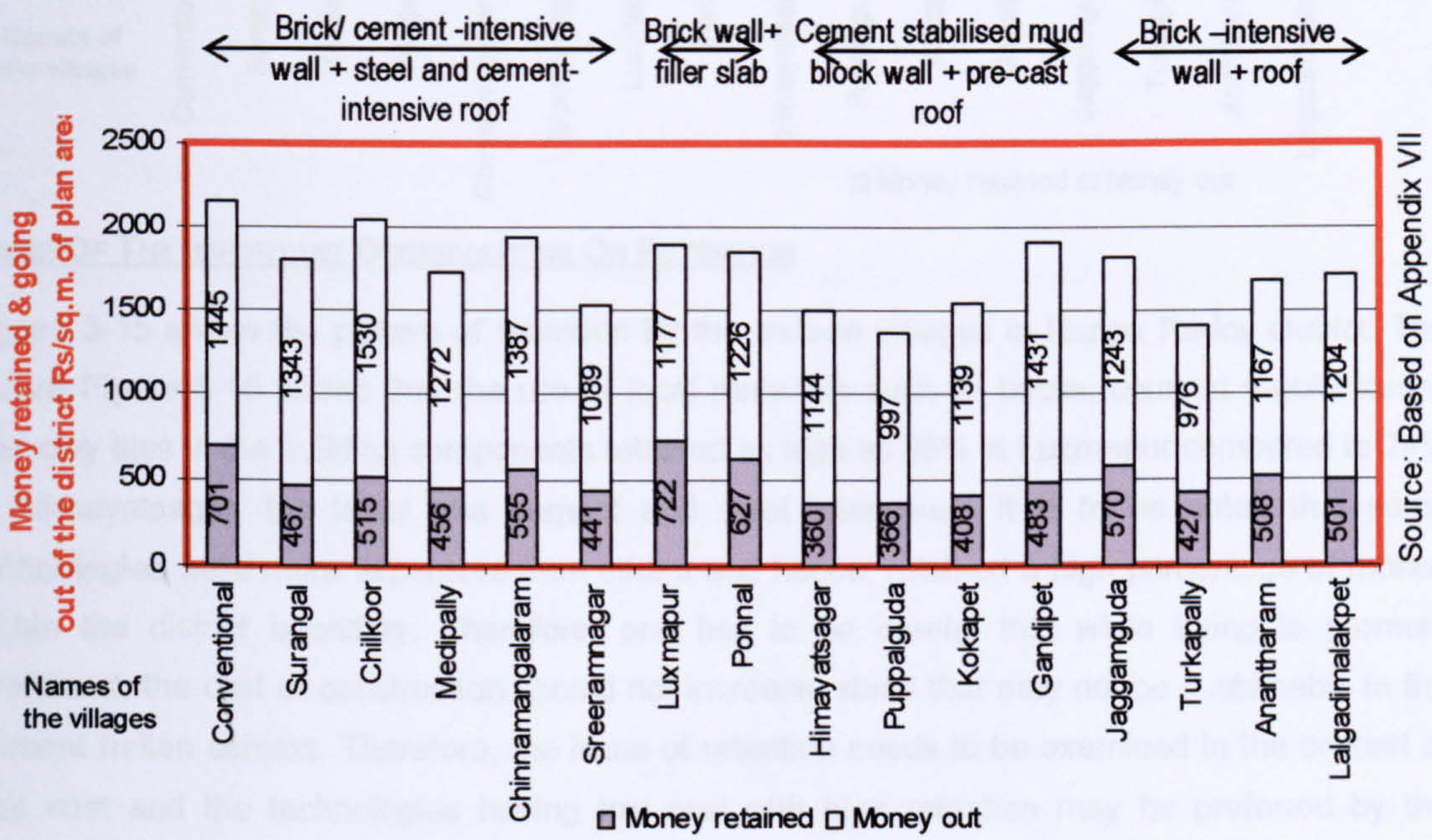
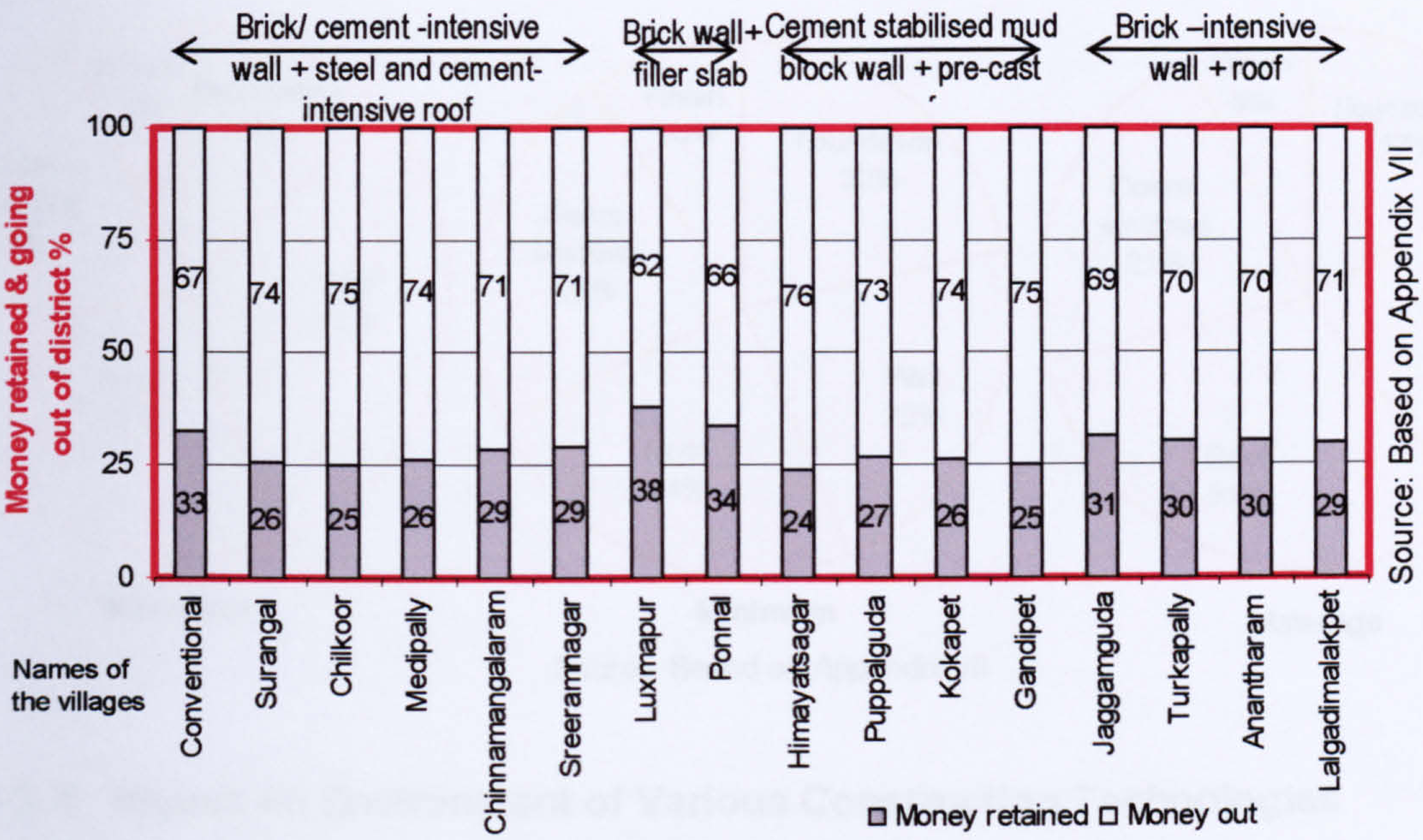


Figure 5-16 The percentage of money retained in and went out of the district at different sites of Ranga Reddy district.

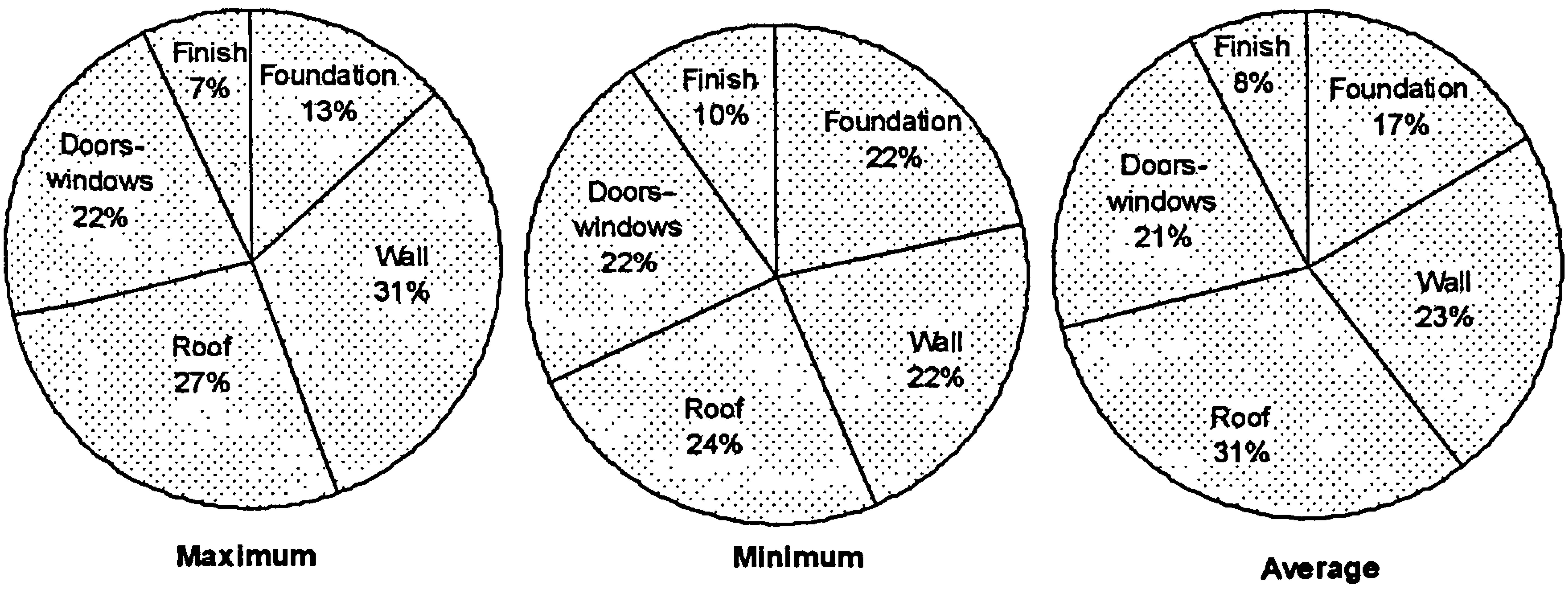


<u>**SOME OF THE IMPORTANT OBSERVATIONS ON RETENTION**</u>

Figure 5-15 shows the pattern of retention by the sixteen villages in Ranga Reddy district. The above Figure 5-16 shows that the use of local materials such as bricks, coursed rubble stones and clay tiles in the building components retained as high as 38% at Luxmapur compared to 24% at Himayatsagar, the latter was cement and steel intensive. It is to be noted that some technologies were more expensive than others and hence, retained a high percentage of money within the district boundary. Therefore, one has to be careful that while trying to promote livelihood, the cost of construction should not increase, since that may not be sustainable in the present Indian context. Therefore, the issue of retention needs to be examined in the context of unit cost and the technologies having low cost with high retention may be preferred by the decision makers to enhance local employment.

The pie charts in Figure 5-17 show the maximum, minimum and average distribution of total retention per building component. The major portion of the retention is on the foundation, wall, and roof, which constitute a maximum of 71%, minimum 68% and an average of 71% of the total labour cost. Pie charts shown in Figure 5-17 are based on the data from sixteen sites in Ranga Reddy district.

Figure 5-17 The distribution of retention on building components in rural primary schools in Ranga Reddy district



Source: Based on Appendix VII

5.3.4 Impact on Environment of Various Construction Technologies

At present, in India, there is not only a need for low cost construction, it is equally important to view construction as an opportunity for employment generation. However, construction might also be a threat on the environment as mentioned in chapter 4. Therefore, the following sections will examine the environmental impacts of the school construction in Ranga Reddy district. This will enable us to select the appropriate construction technologies in a particular context, which will cause the least damage to the environment.

The impact on the environment has been quantified in terms of non-renewable, renewable and the use of agricultural waste in the procurement of raw materials, production and transportation and the on-site process involved in construction. The non-renewable energy is primarily owing to burning fossil fuels in the entire process of construction from the materials to the on-site process. The renewable energy is depleted while burning of firewood for the production of building materials. Some of the building products, e.g., wire-cut bricks and clay tiles, were produced by using rice husk as fuel in Ranga Reddy district, which was an agricultural waste. Fuel waste from rice husk burning was used as fertiliser by the local people in Ranga Reddy, thus it was environmentally friendly. It may be noted that the conventional walling system adopted clamp bond bricks, which was coal and firewood based. Let us now look at the environmental impacts owing to the school construction in sixteen villages of Ranga Reddy district under Andhra Pradesh Primary Education Project.

Figure 5-18 The embodied non-renewable energy per building component at different sites in Ranga Reddy District (showing the maximum and minimum of each component)

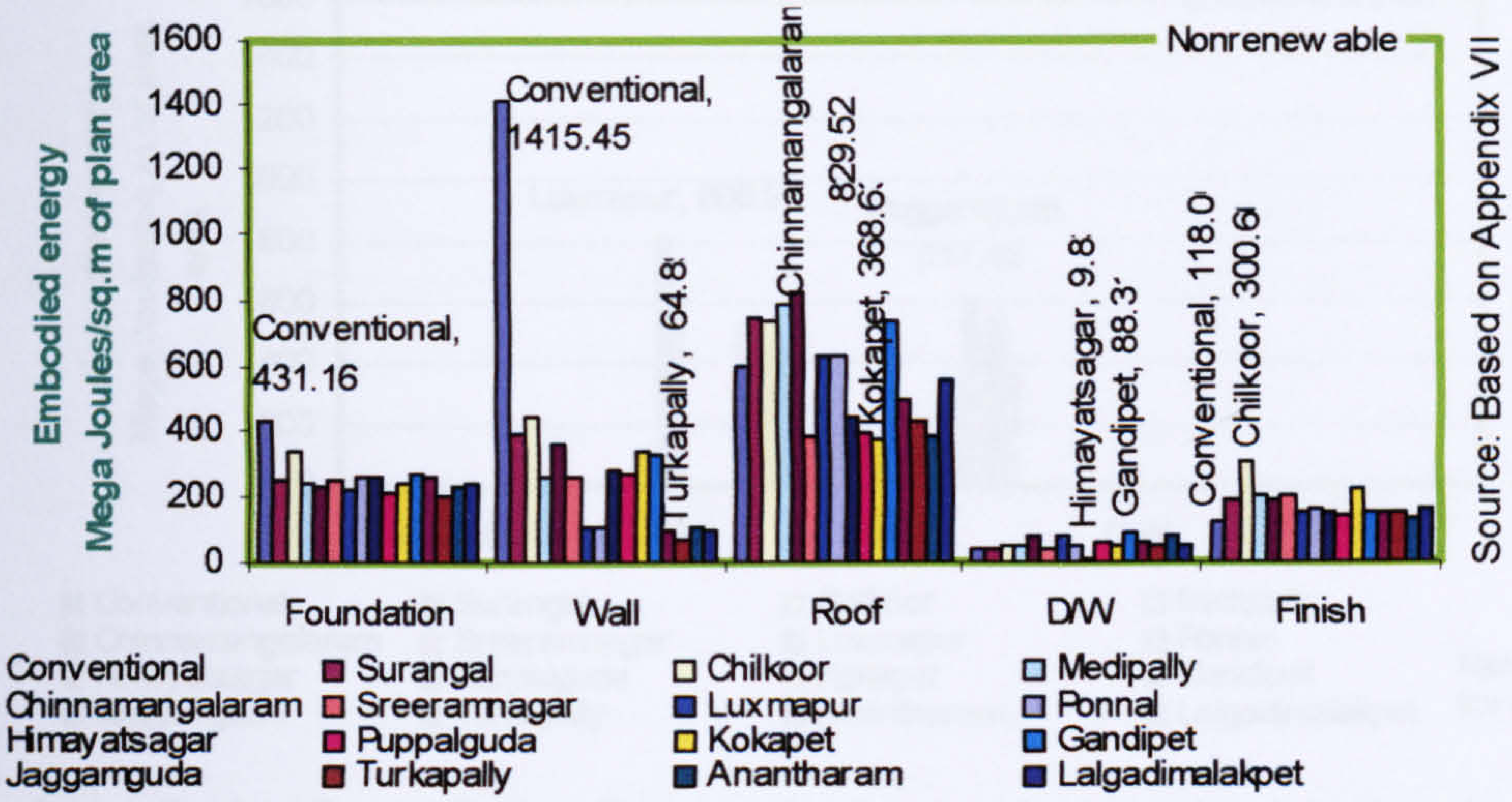


Figure 5-19 The embodied renewable energy per building component at different sites in Ranga Reddy District (showing the maximum and minimum of each component).

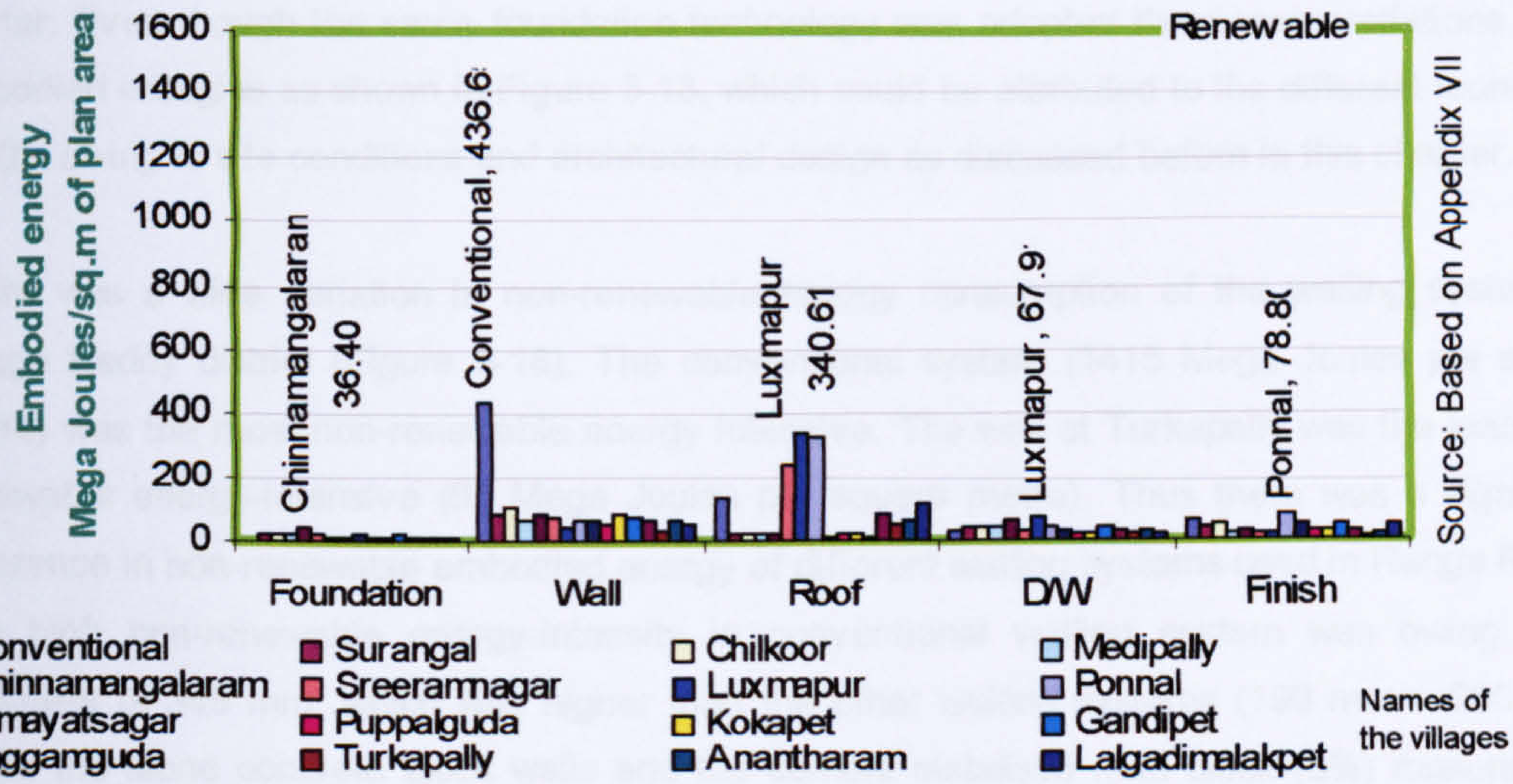
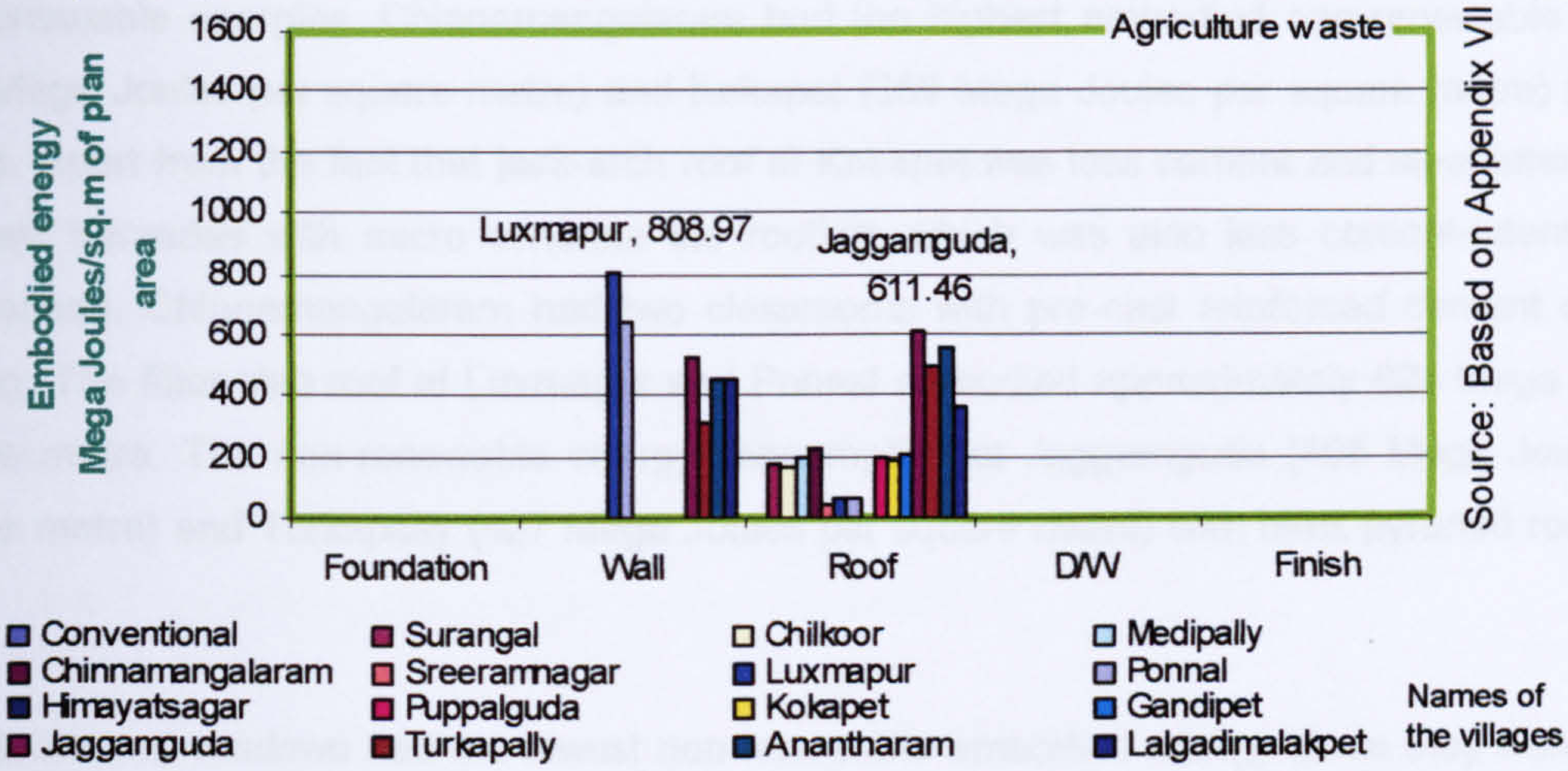


Figure 5-18, Figure 5-19 and Figure 5-20 indicate that the Indian building industry has a high intensity of non-renewable energy compared to the other sources of energy. Figure 5-20 shows that some of the walling and roofing technologies had embodied energy owing to burning rice husk. Such systems had used bricks and (or) clay tiles, which were manufactured in plants run by rice husk as fuel. However, it may be noted that, generally, coal and fire wood are used as fuels for brick and tile manufacturing. Therefore, in most of the contexts in India, the benefits shown in Figure 5-20 will be non existent.

Figure 5-20 The embodied energy owing to agriculture waste (rice husk burning) per building component at different sites in Ranga Reddy District (showing the maximum and minimum of each component).



The foundations in Ranga Reddy district were of coursed rubble stone masonry in cement-sand mortar. The stone blocks being hand-quarried had negligible embodied energy. The major contributor to the non-renewable embodied energy in stone masonry was the cement present in mortar. Even though the same foundation technology was adopted there were variations in the embodied energies as shown in Figure 5-18, which could be attributed to the different foundation depths owing to site conditions and architectural design as discussed before in this chapter.

There was a wide variation in non-renewable energy consumption of the walling systems in Ranga Reddy district (Figure 5-18). The conventional system (1415 Mega Joules per square metre) was the most non-renewable energy intensive. The wall at Turkapally was the least non-renewable energy-intensive (65 Mega Joules per square metre). Thus there was a significant difference in non-renewable embodied energy of different walling systems used in Ranga Reddy. The high non-renewable energy-intensity in conventional walling system was owing to its thickness of 345 mm, which was higher than the other walling systems (190 mm – 230 mm). While the stone concrete block walls and the cement stabilised mud block (5%) masonry had high embodied non-renewable energy, the rat-trap bonded walls were low non-renewable energy-intensive. Rat-trap bonded masonry was constructed with wire-cut bricks, which were produced in rice husk fired kilns and hence, it had low embodied non-renewable energy. The other reason for its low non-renewable energy intensity was the low wall height (2100 mm - 2400 mm) required for the pyramid roof and filler slab. The high energy consumption at Himayatsagar was owing to the use of 10% cement stabilised interlocking block wall with cement-sand mortar. The variation in embodied non-renewable among the same walling systems were owing to the different architectural designs and site conditions as discussed before in this chapter.

Figure 5-18 shows that there was a wide variation in non-renewable energy consumption of the roofing systems. The pre-cast reinforced cement concrete roofs had high embodied non-renewable energies. Chinnamangalaram had the highest embodied non-renewable energy (830 Mega Joules per square metre) and Kokapet (369 Mega Joules per square metre) had the lowest. Apart from the fact that jack-arch roof at Kokapet was less cement and steel-intensive, it had two verandas with micro concrete tile roofing, which was also less cement-intensive. In comparison, Chinnamangalaram had two classrooms with pre-cast reinforced cement channel roofing. The filler slab roof at Luxmapur and Ponnal embodied approximately 624 Mega Joules/ square metre. The non-renewable energy consumption at Jaggamguda (498 Mega Joules per square metre) and Turkapally (427 Mega Joules per square metre) with brick pyramid roofs was low.

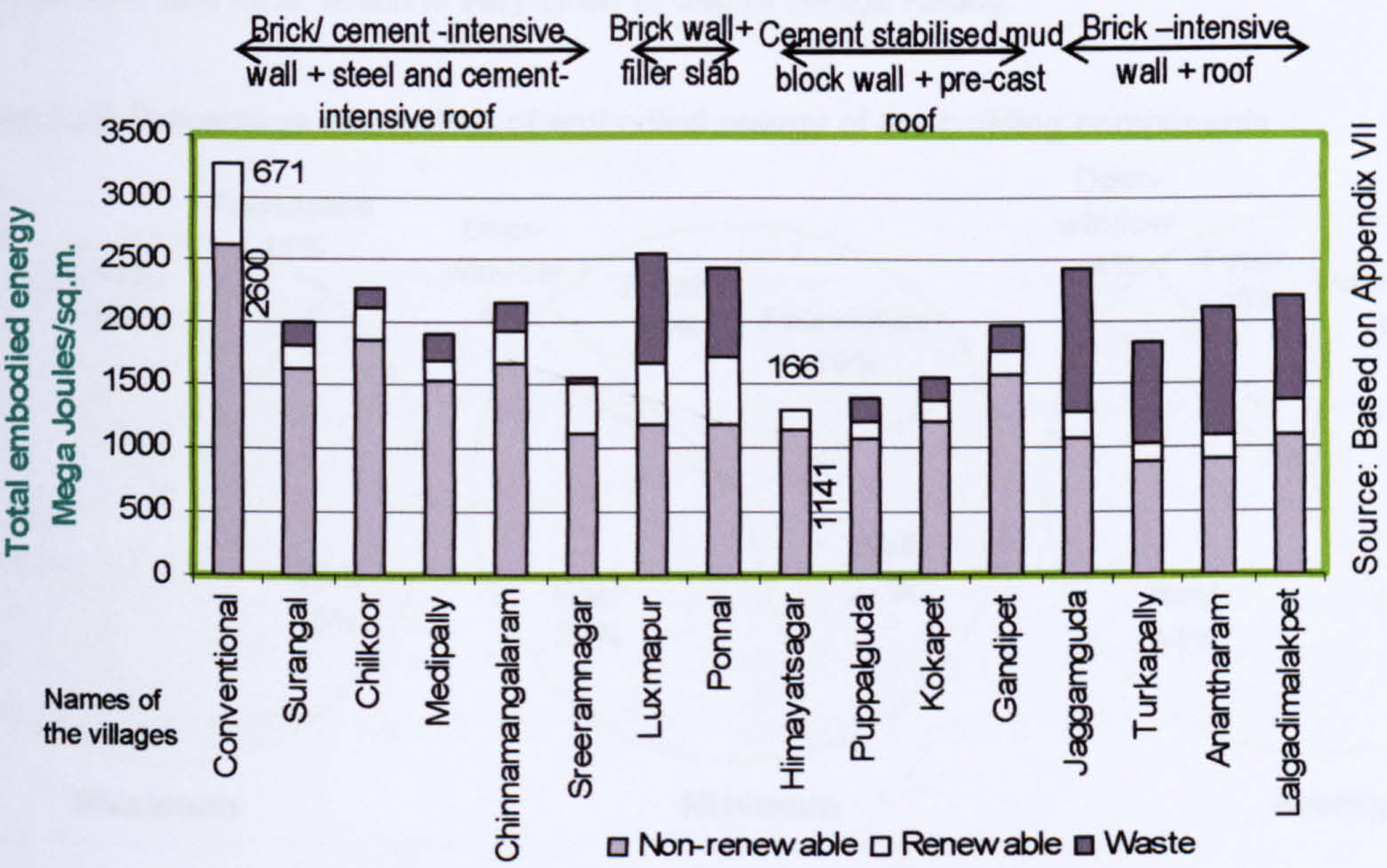
The doors and windows had the lowest non-renewable embodied energy since they were made of local timber. In comparison, the finishes had higher levels of non-renewable energy consumption because cement was used under the stone floor and plastering, and lime was used for painting.

Figure 5-19 shows that the use of renewable energy was only visible in roofs and walls that had used bricks or clay tiles. The roofs that required wooden shuttering materials had consumed some amount of renewable energy. The doors and windows also had embodied renewable energy.

Wire-cut brick manufacturing in Andhra Pradesh uses rice husk as fuel. There are many rice mills in the villages and the waste product is used as fodder and also for brick burning. The waste product that came out of the brick kilns were used as fertiliser and also a part of it was mixed with the clay for brick manufacturing, which made the bricks lighter. Therefore, wherever Figure 5-20 shows the consumption of agricultural waste, it indicates that wire-cut brick and/or clay tiles were used in that component of the buildings. Therefore, brick intensive systems used in Luxmur, Ponnal, Turkapally, Jaggamguda, etc., were the least damaging to the environment and may be encouraged.

Let us now look at the embodied energy of buildings calculated in other contexts. Treloar et al (2001) calculated embodied energy of residential buildings in Australia by using different methods of analysis. When they had calculated according to the Input-Output based Hybrid method of analysis, the embodied energy was 14,300 Mega Joules per square metre. According to the Input-Output method, the embodied energy came out to be 6,800 Mega Joules per square metre, which is less than half of the previous value. Treloar et al refer to Pullen (1995) and state that the latter's studies in Australian residential buildings averaged around 5,500 Mega Joules per square metre. Therefore, embodied energy in buildings may vary considerably depending upon the different methods of analysis and local conditions in different countries. This issue has been discussed in chapter 2. Such differences in embodied energy, according Cole and Rousseau (1992), are owing to the system boundaries, data source reliability, international differences and thermal energy content of feedstock materials adopted in the method of analysis. Let us adopt the least value of embodied energy as 5,500 Mega Joules per square metre for comparison with Andhra Pradesh. The total embodied energy per square metre of the schools at Ranga Reddy varied between 3276 to 1309 Mega Joules with an average of 2293 Mega Joules, which is about half of the Australian buildings (Pullen's value). Therefore, the buildings in Ranga Reddy district may be considered as low energy schools.

Figure 5-21 The embodied non-renewable, renewable and agriculture waste energy per square metre of plan area at different sites in Ranga Reddy.

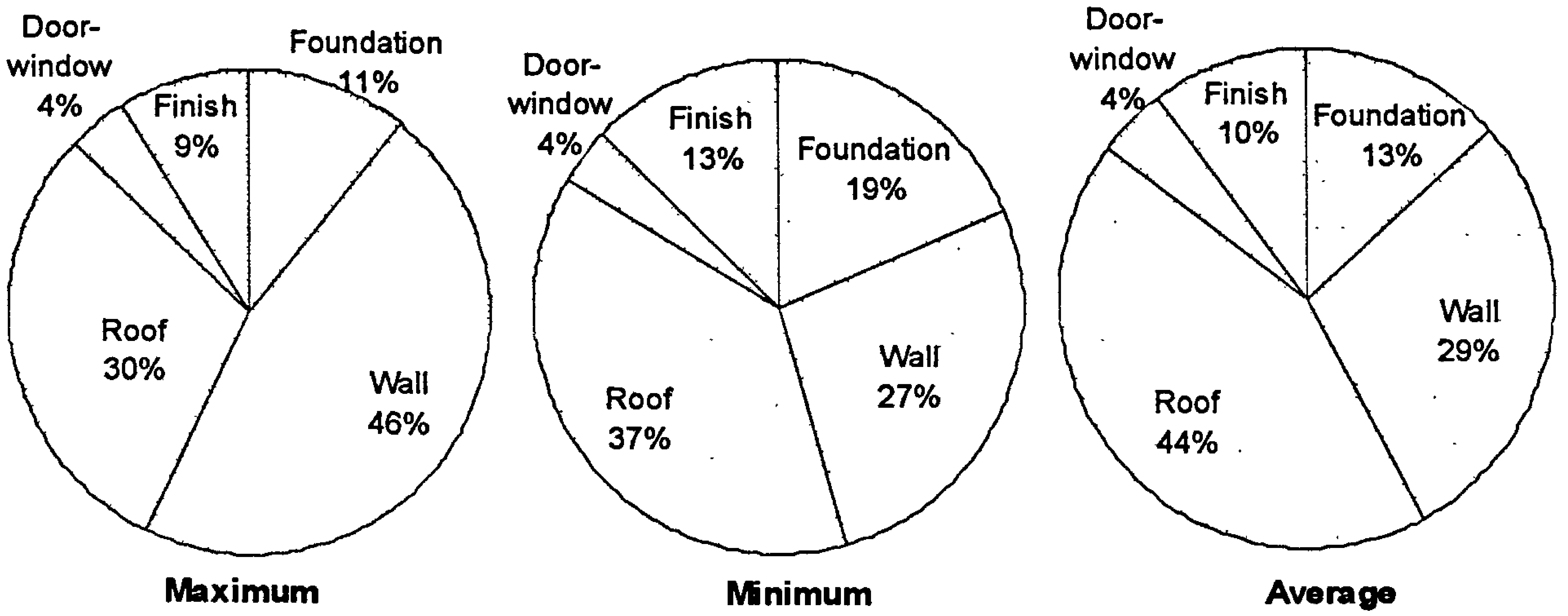


Let us examine the embodied energy in all the sixteen villages of Ranga Reddy district, Andhra Pradesh. Figure 5-21 shows that the technologies adopted in Ranga Reddy were highly non-renewable energy-intensive, compared to that of the renewable and waste. The main contributors of the non-renewable energy are cement and steel. There is a need for reducing cement consumption in construction since India is the fourth largest cement producer in the world (Emission Baselines, 2000). It may be noted that cement depletes non-renewable natural resources. The other contributors of embodied non-renewable energy are waterproofing compound, binding wire, bricks, etc. Apart from that, emission of CO_2 in the production of cement, steel, bricks etc., loss of soil owing to brick manufacturing, etc., are the other important factors that will be analysed later. It may be noted that world wide brick production has been slowed down owing to the continuing concerns of excavating fertile top soil for its manufacture (Camp, 1999). Depletion of diesel owing to transportation of materials may also be significant if materials are transported from a great distance.

<u>SOME OF THE IMPORTANT OBSERVATIONS ON ENVIRONMENTAL IMPACT</u>

The following pie charts show the energy consumption of the different components of the school buildings constructed under the Andhra Pradesh Primary Education Project. The three pie charts in Figure 5-22 show the range of variation of the maximum, minimum and average embodied energy shared by foundation, wall, roof, door-window and finish. It is quite evident that a major contributor of the energy consumption is the wall and roof combined – 73% average. Figure 5-22 is based on data collected from the sixteen sites in Ranga Reddy district. According to Pooliyadda and Dias (2005), the embodied energy of walls (single storey) in Sri Lanka is between 29% and 49%, which is very close to that of Ranga Reddy.

Figure 5-22 Percentage distribution of embodied energy of the building components



(a) Source: Based on Appendix VII (b) (c)

5.4 SUMMARY OF FINDINGS

The experience of the process and database of Ranga Reddy district provides us a large number of technological options for primary school construction. The generally accepted information regarding construction in India are dominated by the average data provided by the Building

Material Technology Promotion Council, the Central Building Research Institute, etc., which provide limited technological options. Whereas, the data acquired from Andhra Pradesh Primary Education Project provides a large number of options of construction technologies. As mentioned in chapter 2, these school construction technologies are applicable in the housing and primary healthcare sectors also. In Andhra Pradesh Primary Education Project, some of the roofing and walling technologies were found to be low cost, labour-intensive and environment-friendly. There was a wide variation in unit cost of construction, labour-intensity and energy consumption of different technologies. However, site conditions, plan form, combination of wall and roof also contributed to such variations.

As discussed in the section on "Analysis by component" the costs per square metre of plan area of the same foundation technology were different at different sites. This was primarily owing to the level of the site and plan form. While the site level determined the foundation-depth, its length was governed by the plan form. Similar variations were also observed within the same walling systems. The length of the wall was determined by the plan form and its height by the type of roofing system. For example flat roofs required a 3 metre wall height, whereas it varied between 1.8 - 2.4 metres for the non-flat roofs.

Architectural designs contributed to the cost of construction as well. For example, semi-open verandas as learning spaces adjacent to classrooms were economic owing to the reduction in volume of walls and numbers of doors and windows. Examples are Turkapally, Himayatsagar, etc. (Appendix VIII).

The above paragraphs have explained the factors affecting cost of construction (other than technologies), which basically reduced the material consumptions and hence, will affect proportionately the labour cost, money retained and embodied energy.

In pre-cast technologies such as plank and joist, channel etc., the economic span for inaccessible roof is around 3600 mm. Classrooms in Ranga Reddy had about 5500 mm width and hence, a central beam had to be introduced which increased room height and cost.

The construction technologies used in Ranga Reddy had high intensity of unskilled labour and non-renewable energy. The walls and roofs consumed most of the costs, energy and labour component. However, the walls built with bricks, which are produced by burning rice husk as a fuel is environment friendly.

The Andhra Pradesh Primary Education Project provides a wide choice of technologies for school, housing and primary healthcare construction. The choice of technologies for a particular place depends upon the material resources available, the production process, the road condition, availability of electricity, available human skill, employment situation, etc. Technologies that are economic and environment-friendly in one place may not necessarily be so in other areas. For example, coursed rubble stone, random rubble, stone slab, aggregate, etc., were available locally in Ranga Reddy district. Excepting stone aggregate that was obtained from an electrically operated stone crusher, all the other types of stones were hand-quarried. Hence, energy consumption for production was very small. Apart from that, the cost of stone-based materials was very low compared to many other states in India, which led to substantial savings in Ranga Reddy. However, sand was expensive since it had to be transported from a distance of 80 kilometres from the sites. Soil depletion owing to brick making in Ranga Reddy had negative impact on the environment since soil for brick making was obtained from the leased land. In a state like Orissa, brick fields are located by the side of rivers and the silt from the river is used for brick making. Thus in the context of Orissa, brick making does not deplete valuable agricultural land. All these factors determine the sustainable technologies in a place; therefore, there cannot be a general solution to all contexts.

Some of the technologies in Ranga Reddy district such as hybrid slab, spiral pyramid, etc., were perhaps constructed for the first time in India. The technological options identified in Ranga Reddy district give an opportunity to the planners, architects, engineers and the Government to adopt sustainable systems in a context. This may enable India to supply the basic minimum services quickly and in a cost effective manner - as Peter Head said *"The new technologies need to be suitable for developing countries so that they can leapfrog the problems that developed countries are creating and reach their goals quicker and at lower cost." Head (2005:17)*

This chapter has examined the impact of different construction technologies (new construction) on socio-economy and environment in the context of Andhra Pradesh Primary Education Project. And it appears that this experience could be utilised to develop a method for developing sustainable social infrastructure in other contexts. This aspect will be discussed in chapter 11. However, it is important to note that life cycle analysis is not possible without historical data on building maintenance requirements. Therefore, the data from the Repair and Upgrading programme of Andhra Pradesh Primary Education Project, undertaken four years after the buildings were constructed, may be important to understand the life cycle implications. The following chapter examines the issue of life cycle implications of different construction technologies used in Andhra Pradesh Primary Education Project.

CHAPTER 6: ANDHRA PRADESH PRIMARY EDUCATION PROJECT- REPAIR AND UPGRADING PROGRAMME

6.1 BACKGROUND

The schools constructed under the Andhra Pradesh Primary Education Project were revisited in 1998. The main objective of revisiting was to examine the performance of the different construction technologies adopted in the schools of Ranga Reddy. This was a unique opportunity to observe the ageing of a variety of materials and technologies in one consistent setting – built at the same time, located in the same climatic zone, having same end-usage and constructed under the same degree of supervision. The intervention cost provided reliable information on the life cycle impacts of the technologies.

Just before Andhra Pradesh Primary Education Project was over, another nationally sponsored programme called District Primary Education Programme was launched by the Government of India in its eighteen states. The main objective of this programme was to achieve universal elementary education in India by 2005 (DPEP, 1995). The major funding for the programme was a soft loan from the World Bank and hence, cost effective classroom construction was a mandate in the programme. Andhra Pradesh Primary Education Project had deeply influenced the District Primary Education Programme. Several of the Technologies used in Andhra Pradesh were replicated under that programme and hence, there was a great demand from the eighteen states for carrying out such investigation so that they do not repeat any mistakes. Revisiting the project in 1998 brought out information on the performance of the technologies adopted in 1995-96, which helped in the dissemination process of cost effective construction technologies in rural infrastructure development.

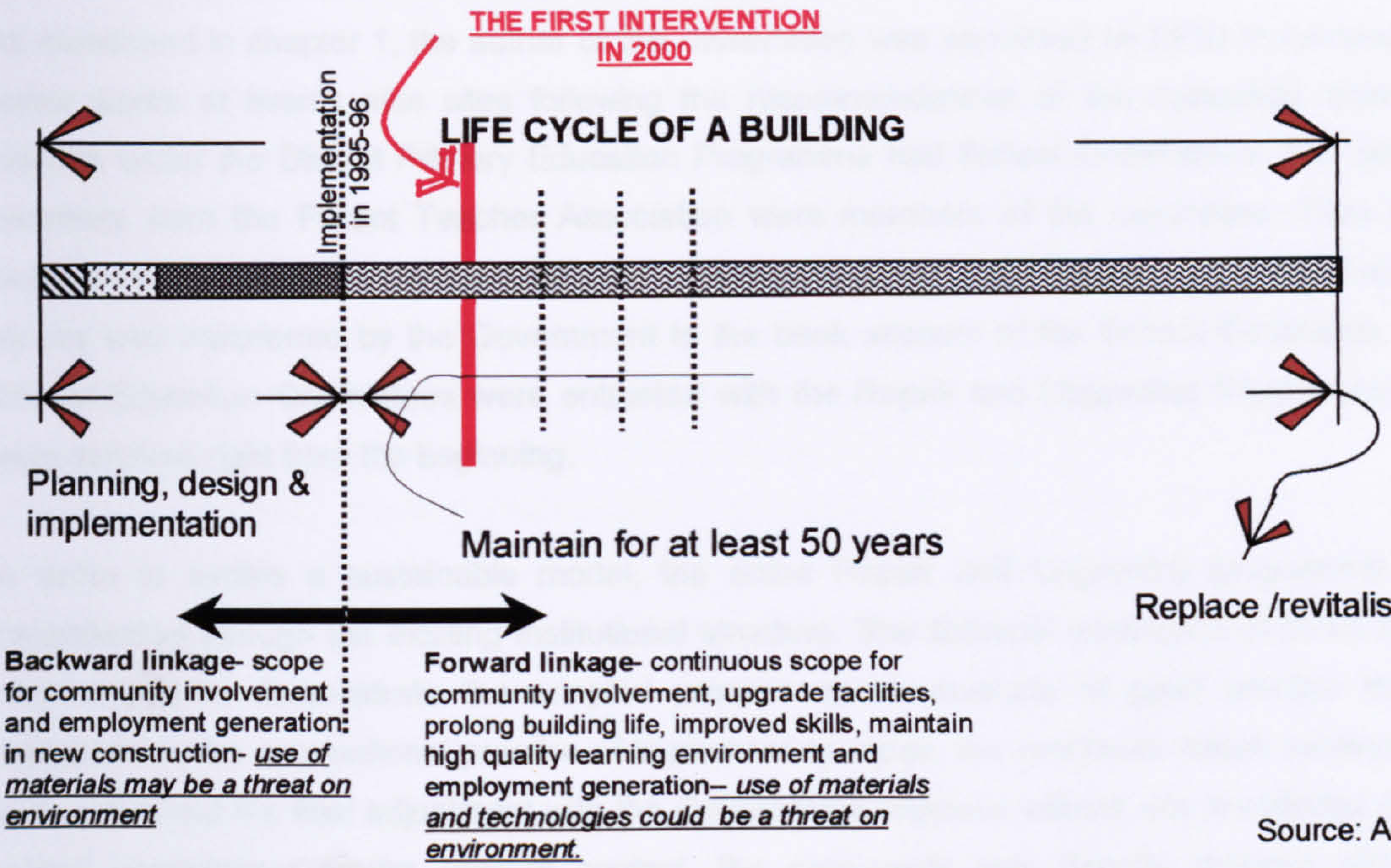
The original concept of Andhra Pradesh Primary Education Project had a similarity with the process suggested by Hawthorne (1978) based on Rogers (1962). Hawthorne mentions that dissemination of technologies needs to be based on an identification of the kind of information which the ultimate user should require. Rogers describes the user's needs in terms of an "adoption process". This is defined as the "mental process" through which an individual passes from first learning about an innovation to final adoption. Rogers conceptualizes this process in five stages.

1. Awareness – the phase when the individual first hears of the innovation but lacks full information about it.
2. Interest – the stage when (s)he deliberately seeks out the missing information.
3. Evaluation – when (s)he mentally considers the use of the innovation and makes the decision where to try it.
4. Trial – the practical, usually small scale, test to assess the value of the innovation to his present and future situation.
5. Adoption – the phase when the trial is extended to full use of the innovation.

The Repair and Upgrading programme was at step 4. It may be noted that Ranga Reddy was included in the District Primary Education Programme and, according to its regulations; each school had a School Committee to look after the education and infrastructure aspects. Existence of the School Committees was an added advantage for a repair programme since it intended to involve the community to increase ownership of the school buildings, to ensure adequate housekeeping and future maintenance. Therefore, the District Collector of Ranga Reddy was informed that the Repair and Upgrading programme of the existing cost effective schools will be implemented by the respective School Committees. The objective was to test the model of community-based Repair and Upgrading of education infrastructure so that the schools constructed under the District Primary Education Programme could adopt the same process with local specific modifications.

Figure 4.6 of chapter 4 has been modified and recast in Figure 6-1 to demonstrate the implications of the Repair and Upgrading programme. The dotted vertical lines in the diagram indicate the frequency of the interventions, which was expected to be one of the outcomes of the programme. Figure 6-1 shows the first on-site intervention in 2000, which was about four years after the construction of the schools. The programme was also designed to understand the extent of forward linkage. The entire process of Repair and Upgrading programme has been analysed to understand all these aspects to provide information on sustainable construction technologies for the development of primary education infrastructure in Andhra Pradesh, which in turn could be adopted in the rest of the country with locally specific modifications.

Figure 6-1 The forward and backward linkage in the life cycle of a building.



Source: Author

6.2 THE EVALUATION

Prototype schools constructed at twenty nine sites in 1995 - 96 had adopted the following systems;

- Eleven types of roofing systems
- Six types of walling systems
- One type of foundation system

The evaluation was carried out between 14th October and 23rd November 1998. The multi-disciplinary team consisted of specialists from the National Council of Cement and Building Materials, India and DFID nominated UK based consultants with specialist background in Building Sciences and Social Development. The team met the civil works consultants, Government engineering personnel and other related Government functionaries, who had been connected with the cost effective construction technologies project in Ranga Reddy district, and undertook an extensive field study. They studied the architectural designs, construction methods and cost effectiveness in terms of maintenance. The evaluation determined aspects of technology and design performance, maintenance requirements, etc., to aid future projects. It also identified the needs for repairs, structural correction and improvement of climatological performance of some of the prototype buildings.

6.3 THE REPAIR

As mentioned in chapter 1, the author of this dissertation was appointed by DFID to carryout the repair works at twenty nine sites following the recommendations of the evaluation team. All schools under the District Primary Education Programme had School Committees. The elected members from the Parent Teacher Association were members of the committee. They were headed by the School Committee Chairperson, who was a non-teaching member. School-related money was transferred by the Government to the bank account of the School Committee. The School Education Committees were entrusted with the Repair and Upgrading Programme and were involved right from the beginning.

In order to evolve a sustainable model, the entire Repair and Upgrading programme was implemented through the existing institutional structure. The financial assistance of DFID in this context was to demonstrate the adopted process as an example of good practice that is replicable. In the conventional practice of implementing repair, the contractor raises running bills and carries out the final adjustment with the Government engineer without any knowledge of the school committees. In the present context, the community was directly involved with the programme and also maintained detail of expenditure on a day to day basis. It was a totally bottom-up approach as a sharp contrast to the conventional practice.

6.4 THE PROCESS

Let us now look at the process adopted in the programme. The evaluation report (DFID, 1998) was used as the baseline information. However, a more rigorous reappraisal of the school buildings was carried out by the author with the help of the School Committees. This needed a series of meetings with the communities to make them aware of their roles and responsibilities, the need for transparency, quality control, cost savings, etc.

Defects of the buildings were identified and mapped by the author for each school with the help of Government engineers and the communities. The Government engineers also needed capacity building in defect mapping. The new system that was community-centred, needed more participation of the engineers than the contractor-based system. It was difficult for the farm labourer parents to come forward and attend the meetings. To suit their requirements, sometimes the meetings were organised early in the morning before they left for the agriculture field. The following is a description of the process of implementing the Repair and Upgrading Programme in Ranga Reddy district of Andhra Pradesh.

6.4.1 Capacity Building of Panchayati Raj Engineering Department and District Primary Education Programme Engineers

A two-day capacity building workshop was organised by the author at the DFID office of Hyderabad in March 1999. The participants ranged from assistant architects to engineer-in-chief. The main objective of the exercise was to develop inquisitiveness among the young engineers through formal methods of condition survey, defect diagnosis and possible recommendations. It was participatory and had generated interest among the participants including the senior engineers present in the workshop. After the basic theoretical input, the author organised a hands-on exercise on deficiency survey at the school sites in Ranga Reddy district, which were constructed with cost effective technologies. Interaction with the communities was useful for understanding and diagnosis of various deficiencies. The school teachers and the students were aware of the defects in their buildings from their early stage. Since they were not involved with the condition survey, they had no opportunity to share this knowledge with the engineers.

6.4.2 Deficiency Survey

The author, with the help of the Government engineers and the communities, carried out deficiency survey. Several meetings with the schoolteachers, students and villagers helped in identifying the technical as well as design deficiencies of the school buildings. Before embarking on the deficiency survey exercise, the existing technologies were studied in detail. The design calculations of all the items were reviewed to recapitulate the idealisations and assumptions of the structural behaviour of the cost effective systems. Apart from that, openings and non-structural elements like doors, windows, etc., were also studied under separate heads. The detail of defect mapping is in Appendix VIII.

6.4.3 Defect Analysis and Recommendations

When the cost effective construction technologies under Andhra Pradesh Primary Education Project (1994-95) were being scrutinised by the Panchayati Raj Engineers, their main doubt was on the structural soundness of the technologies. Though, the structural stability of the technologies was established by calculations, lack of confidence was observed about the actual performance of the buildings under various loading conditions.

The primary school buildings were constructed between July 1995 and August 1996. The deficiency survey carried out in 1999 revealed that the cost effective construction technologies were, structurally, as sound as the conventional systems. The survey report also revealed that the community has in general appreciated the climatic comfort of most of the cost effective buildings.

Let us now analyse the defects. The expected life span of structures may be reduced because of deterioration of concrete owing to poor workmanship, bad quality of materials, inadequate cover, faulty design, etc., (Vaidyanathan et al, 2000). The Repair and Upgrading programme of the buildings in Ranga Reddy district also revealed that the defects over time were also owing to the similar reasons observed by Vaidyanathan. Close examination of the Ranga Reddy building components showed that some of the defects needed immediate corrective actions. Otherwise these would lead to rapid deterioration of physical condition. This type of defects was termed as **"Essential"**, e.g., soakage and (or) leakage through roofs, eroded bricks, eroded cement stabilised mud block and the like. While analysing the root cause of such defects it was found that "Essential" maintenance may be attributed to faulty design-detailing, use of low quality materials and/or workmanship. A project-wise data in this regard in presented in Appendix X.

Painting of doors and windows were termed as **"Preventive"**, as lack of these leads to slow deterioration of physical condition over time. Most of the schools were in acceptable condition and painting was not necessary. However, all the buildings were painted to make them look more attractive, especially to the children.

The Repair and Upgrading programme was not restricted to the repair of the defects of the buildings alone. It probed into the design aspects of the spaces too. The latter revealed many interesting aspects of the classroom spaces, which are sometimes missed out by the designers. For example, incorrect orientation of the buildings at Kesavpur, Himayatnagar, etc., allowed disturbing direct sunlight into the learning spaces. As a result, the schoolteachers were constrained to shift the classes to other sheltered areas. In order to make such spaces usable, "brick jaali", a perforated masonry wall, was recommended. To overcome such problem in Kesavpur, the community decided to plant a tree at a convenient location so that it would stop the direct sunlight in the classroom.

Use of visual campaign for the community as well as the classes was widely used to make the school more attractive, lively and vibrant place of learning. This type of expenditure has been termed as **"Miscellaneous".** The most important observation during the field investigation was the general lack of awareness for **housekeeping.** Appendix IX presents a detail report on of the deficiencies all the school buildings in Ranga Reddy district.

6.4.4 Estimation

A simulation exercise was conducted to estimate rates for repair items. Suitable margin was kept to take care of uncertainties, e.g., a mason takes about ten minutes to chisel out an eroded brick and another ten minutes to replace it. At this rate, (s)he could repair about twenty bricks per day. However, it was decided that such data should be verified during implementation, so that a reliable rate analysis could be evolved to enable estimation of future repair projects. Based on the simulation exercise, the rates of repair items were calculated and the estimation of the Repair and Upgrading was carried out. Table X.2 of Appendix X shows the estimated costs for all sites.

6.4.5 Capacity Building of School Committees

The first item under the implementation was awareness and capacity building of the end-users. Site planning and management of repair work was explained to the School Committees. Each school was provided with a site data book and the School Committees were trained to fill in data on a daily basis (Appendix XVII). Following this, the School Committees collected general data such as cash in, expenditure, keeping the master roll for the masons, etc., and kept meticulous records of daily progress with details like materials and labour components required for a particular type of work. Close observation of each school revealed that the data was authentic.

6.4.6 Implementation

The engineers of Ranga Reddy district was involved with the programme. They used to manage time out of their busy schedule to visit the implementation work. It may be noted that repair, especially a community based implementation programme, is supervision-intensive initially and hence, needed adequate guidance from the Government engineers. By the end of third week of April, 2000, many schools completed the repair work. The completed school buildings brought in a sense of achievement among the School Committees and the final product became an element of pride to the villagers.

6.5 MAJOR FINDINGS OF THE REPAIR AND UPGRADING PROGRAMME

The Repair and Upgrading Programme of Andhra Pradesh Primary Education Project was intended to document data on life cycle impacts of different construction technologies, especially focused on cost, employment opportunities and environment. When the schools were constructed in 1995-96, the communities' roles were not very significant since they were not officially empowered to make decisions. However, the implementers took the consent of the community from time to time. In the Repair and Upgrading Programme, the community was directly involved with the programme that had brought forward many additional features including the life cycle impacts of different technologies. The process of community involvement has been put forward as background information for ease of understanding the context of life cycle impacts of the technologies. The analysis of Repair and Upgrading has been done in the following sequence.

- Important observations on community involvement,
- Repair as a social opportunity – livelihood
- Data base as a feedback to the designers, users and project managers
- Life cycle Impacts

6.5.1 Important Observations on Community Involvement

The experience of community-based repair work reveals that it has reduced cost, helped in quality control, maintaining transparency and, above all, developed ownership of the school buildings. The day to day experience of working with the schoolteachers, students, the villagers and the engineers were recorded. The following are some of the important observations on the key stakeholders, which will help in understanding the complexities of a social infrastructure maintenance programme.

<u>SCHOOL TEACHERS</u>

A series of discussions took place at each school regarding integrating Teaching Learning Materials with the civil works maintenance (Appendix XI). The schoolteachers and the students were storehouses of ideas, e.g., the maps were drawn by the teachers of Kesavpur on a blank wall close to the main entrance for the benefit of the community (Appendix XI). The schoolteachers motivated one Class V student to draw a water filtration process for the awareness of the community. The quality of such work is excellent and these have been mostly drawn on the boundary walls so that the community can visually access these campaigns. Appendix XI shows all these aspects.

<u>SCHOOL COMMITTEE</u>

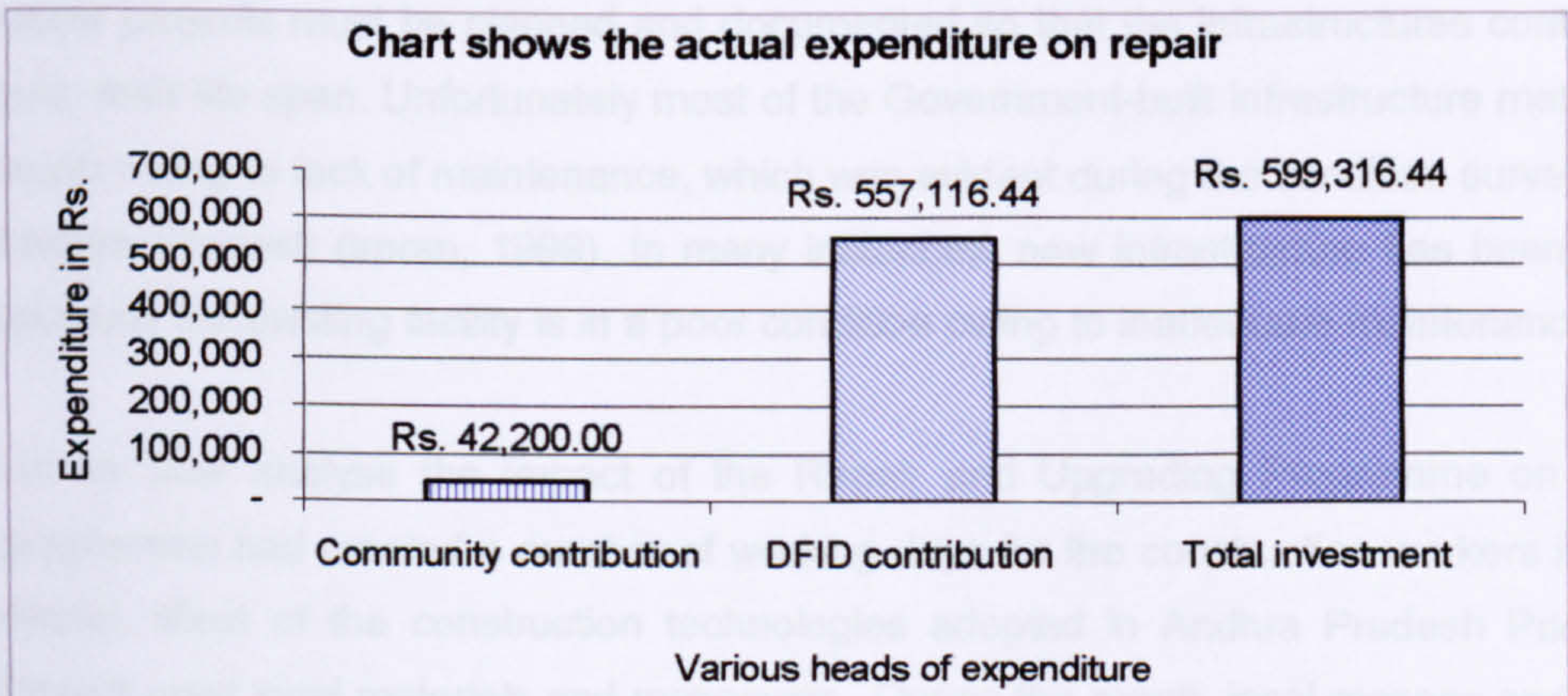
In general, the School Committees showed interest in the repair work; but they were not too comfortable with the involvement of the school teachers in the implementation work. It is interesting to note that the schoolteachers wanted transparency, whereas the School Committees were reluctant to keep records. Some of the village-heads (sarpanches) were more vigilant about what was happening in the schools to show their authoritative position, but they were of little help in repair work.

February, March and April are the auspicious months for marriage in Andhra Pradesh. Hence, in these months, many schoolteachers and the School Committee members were busy in attending marriages of their friends and (or) relatives. Schoolteachers, masons and School Committee members stopped coming to the schools for two to three days at a stretch. This hindered the progress of the repair work.

Cost Savings by the communities: It is important to note that the involvement of the communities in the present programme had reduced cost of repair work in many respects. Cost savings by negotiation with the material suppliers and the masons, etc., could not be quantified, although the amount was significant.

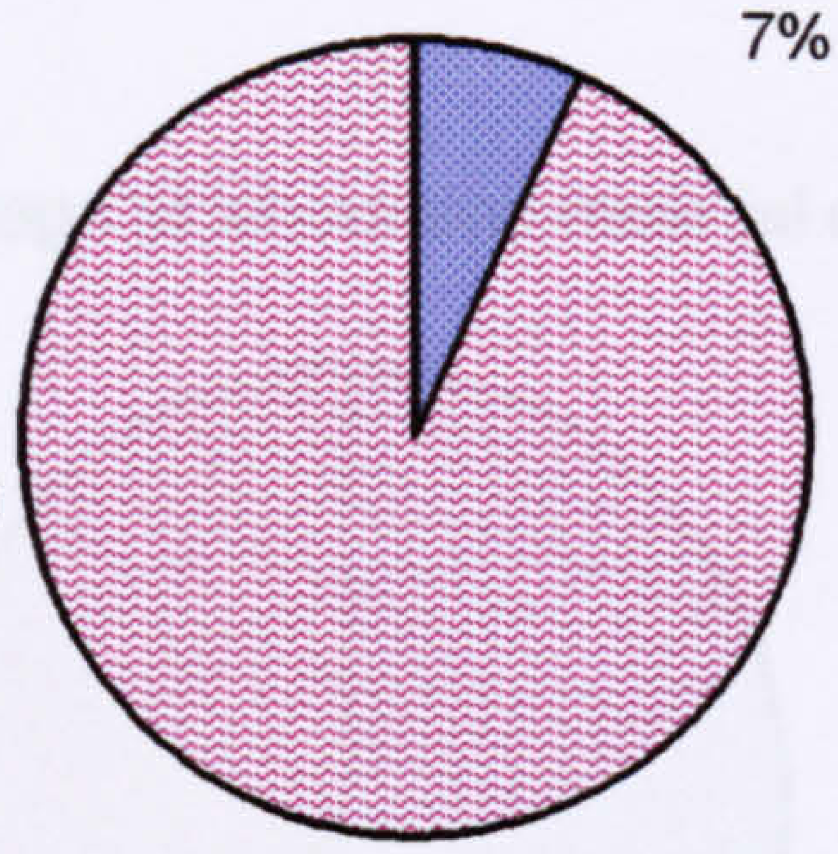
Direct cost-savings by active participation of the schoolteachers and students in the repair work was monitored and recorded. Approximately Rs.42,200 (£528) (Figure 6-2) was generated by the communities as a whole in the entire programme. Considering the poverty in Ranga Reddy district, the community generated savings is very significant and was an indicator of involvement and ownership.

Figure 6-2: Community contribution and DFID investment on Repair and Upgrading Programme (1999-2000). (Rs.80 = £1)



Source: Based on Appendix X, Table X.8

Figure 6-3 The pie chart shows that the community contribution as an indicator of sustainability of the process.



Source: Based on Appendix X, Table X.8

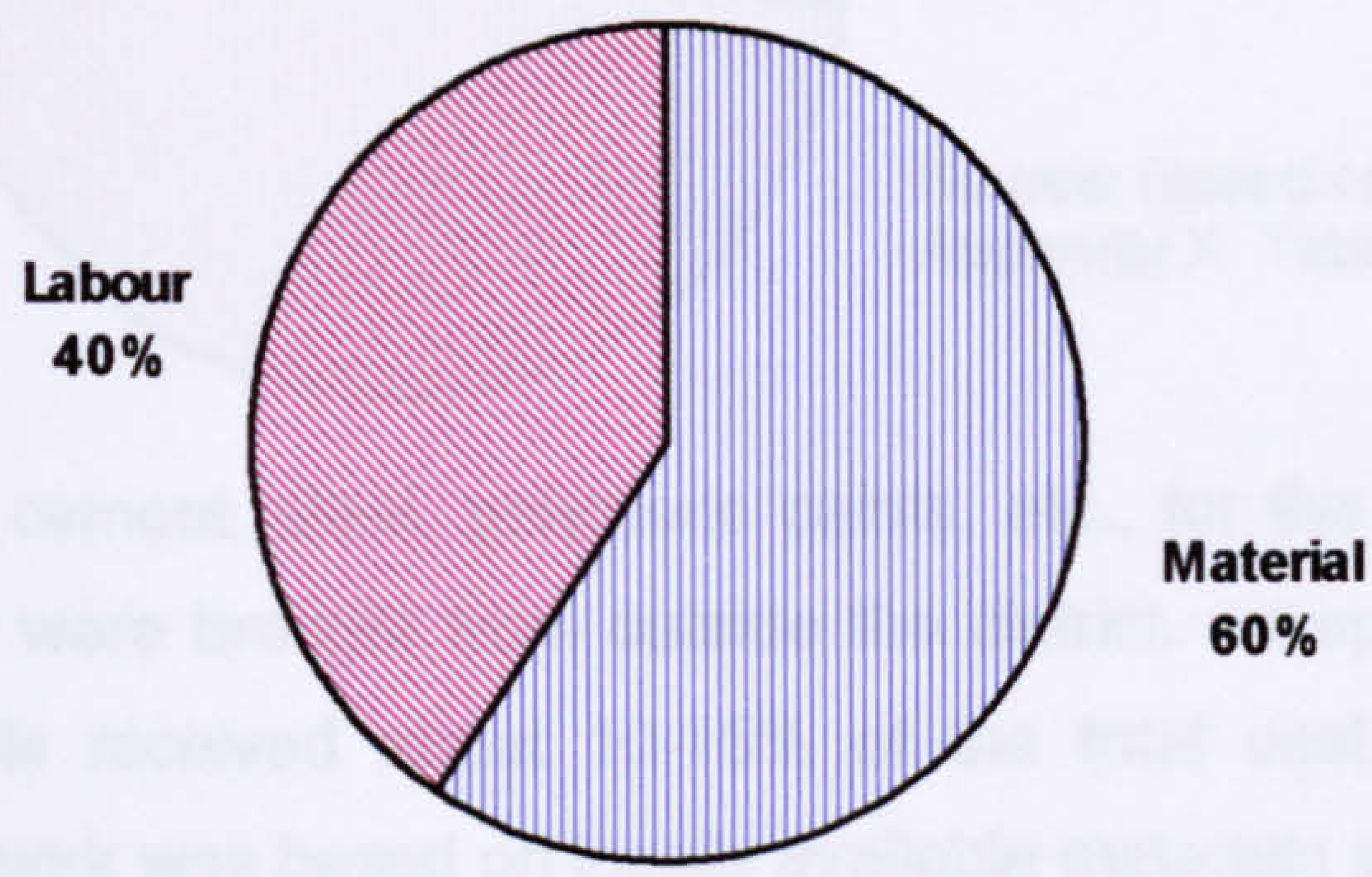
<u>Some notes on ownership, transparency and capacity building:</u> School Committee meetings were held at all the schools for sharing information on the expenditure on repair. Apart from the Parent Teacher Association, villagers had also participated in the meetings. Many issues on school development were discussed and a sense of belonging to the school was observed to be in the process of development. The active participation of the community in the planning and execution of the repair works increased their capacities for future repair works.

6.5.2 Repair as an Opportunity for Livelihood

Repair is usually viewed as a liability by most of the Government engineers in Ranga Reddy. However, the experience of Repair and Upgrading programme has shown that it is an opportunity for local livelihood, enhancing construction skills, extending life span of the building etc. The repair projects must be planned and documented so that the infrastructures continue to function over their life span. Unfortunately most of the Government-built infrastructure met with premature death owing to lack of maintenance, which was evident during the condition surveys conducted in Andhra Pradesh (Imran, 1999). In many instances, new infrastructure has been created simply because the existing facility is in a poor condition owing to inadequate maintenance.

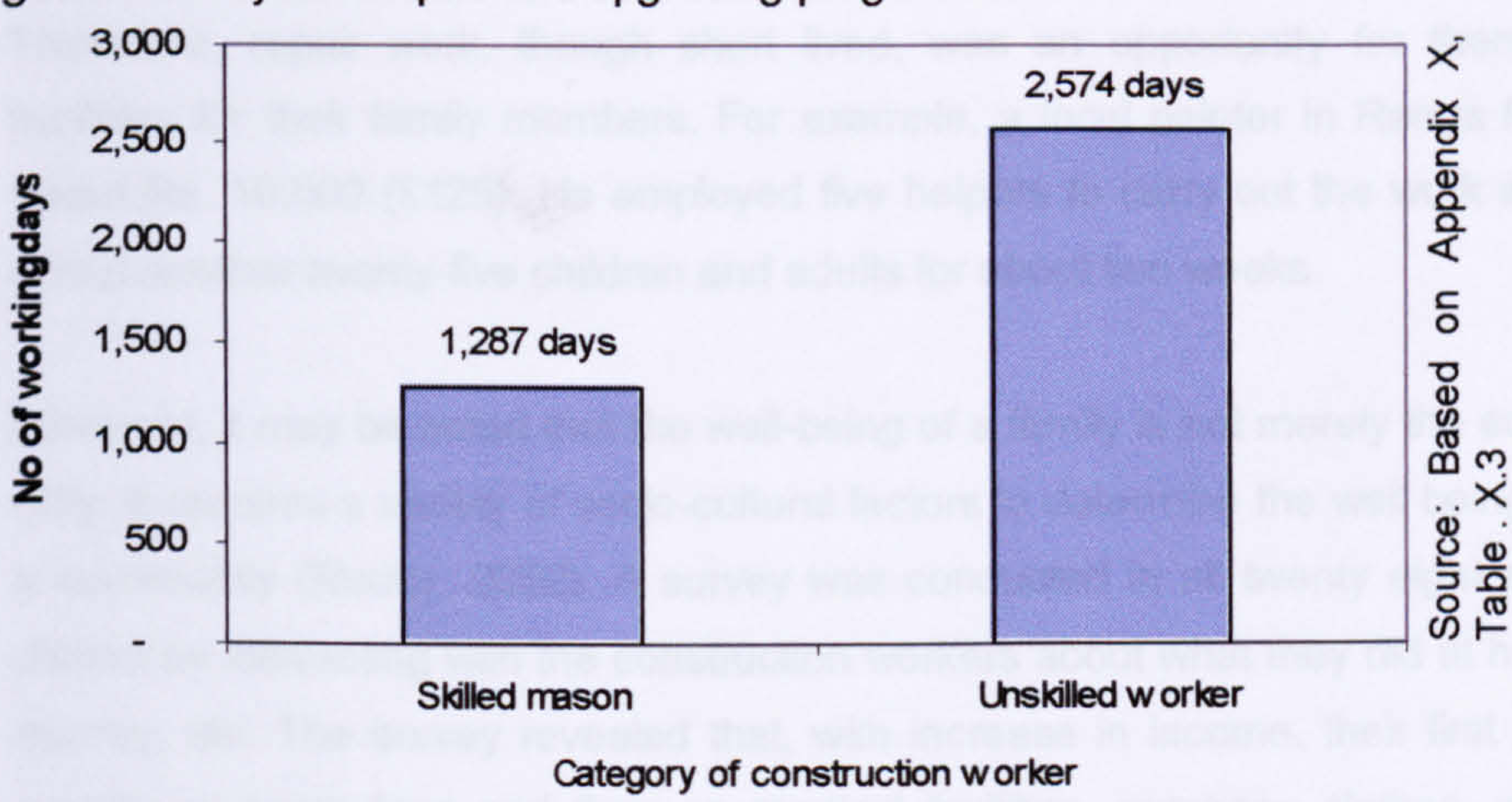
Let us now analyse the impact of the Repair and Upgrading Programme on livelihood. The programme had created a number of working days for the construction workers in Ranga Reddy district. Most of the construction technologies adopted in Andhra Pradesh Primary Education Project used local materials and manpower. During the repair, local masons and labourers were engaged for about four months. The following pie chart shows that 40% of the investment on the present project went to the local masons and labourers (Figure 6-4). On a comparative basis, if there are two technologies with the same unit cost of construction, the one that offers more working days to the masons and helpers, would be preferable in the Indian rural context. However, one has to examine the Life cycle implications in this regard. It should be noted that each working day of a construction worker on an average supports food and other expenses of a family of five.

Figure 6-4: The average percentage of labour and material cost in repair



Source: Based on Appendix X, Table X.3

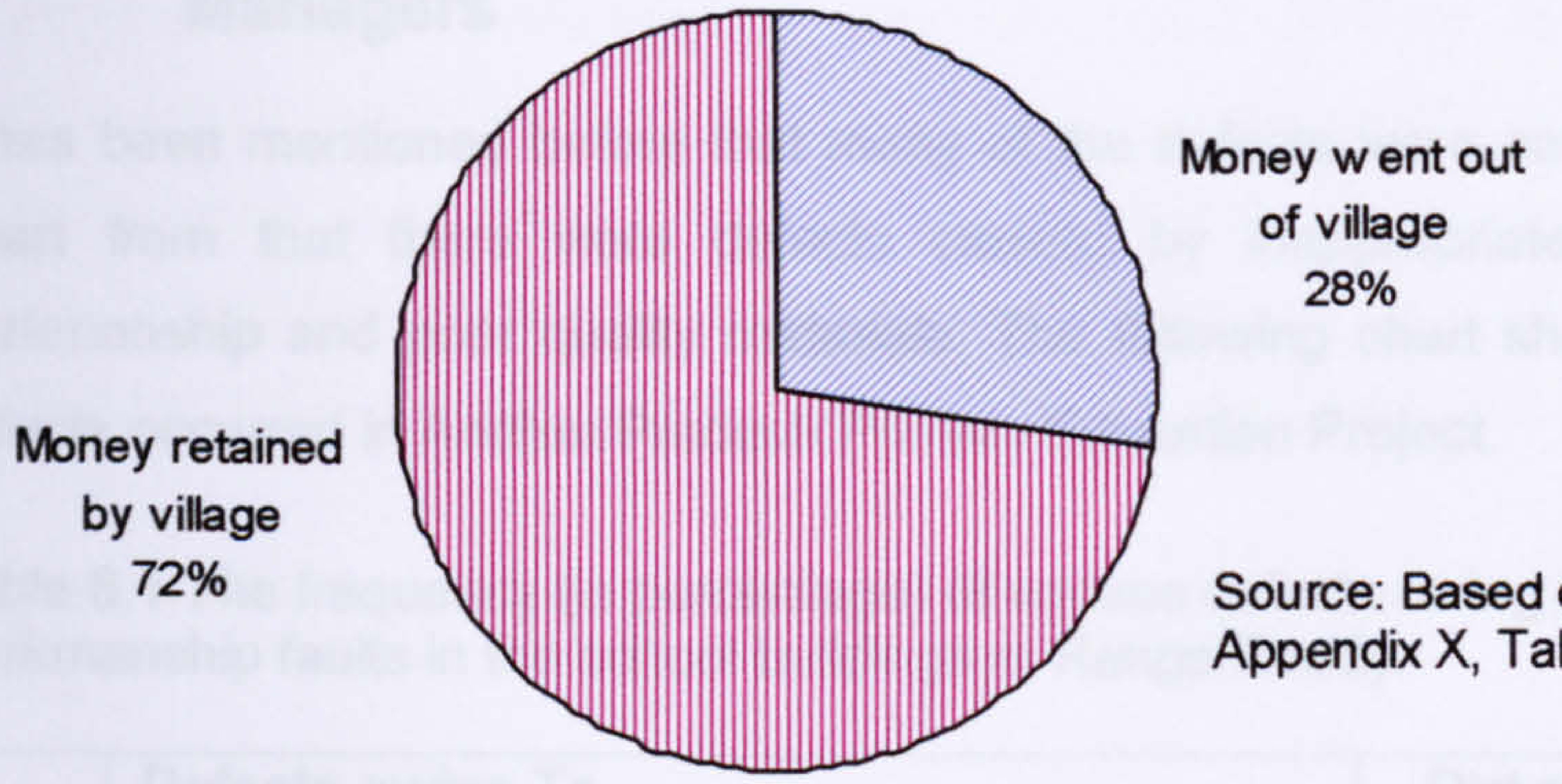
Figure 6-5 The employment opportunity of one skilled mason and two unskilled workers generated by the Repair and upgrading programme



<u>SKILL ENHANCEMENT</u>:

The masons selected for the Repair and Upgrading Programme were taken to the school sites and the causes of defects were explained to them, e.g., use of materials not conforming to the specifications, inadequate curing, etc. In a few villages, the masons who originally constructed the schools in 1995-96, joined the repair work. Thus they had the opportunity to have a close look at the workmanship-related defects of their own works. In the process, skill enhancement has been observed in terms of quality of the repair works. The purpose of this exercise was to train the masons so that they could act as local resources for future repair works at district level.

Figure 6-6 The impact of Repair and Upgrading Programme on local level livelihood.

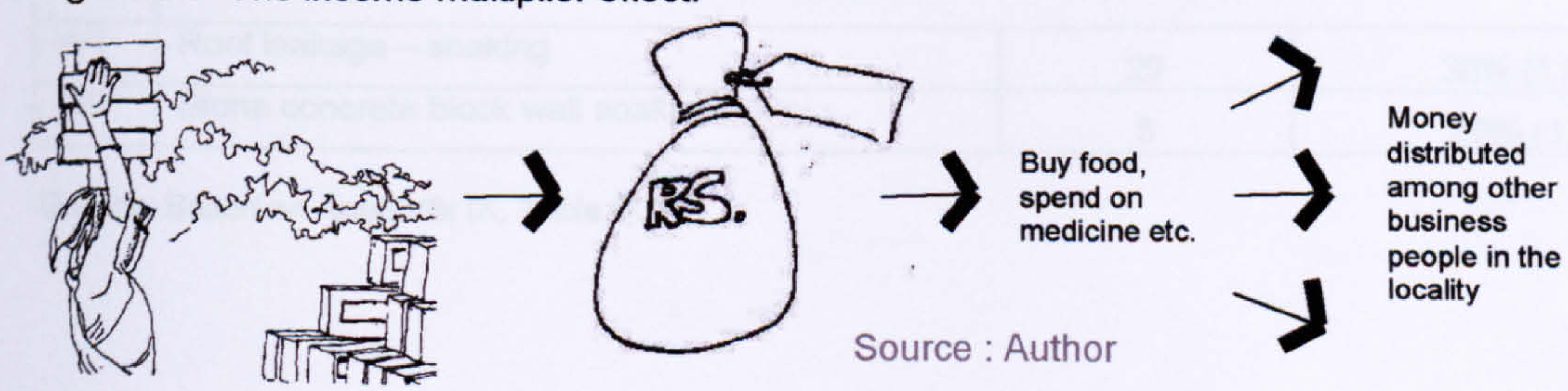


Source: Based on Appendix X, Table X.5

The investments on cement, steel, polymeric paints, etc., for the repair works went out of the villages, since these were brought from outside the district, except that the local distributors of construction materials received about 10-15% of the total cost of the materials as agency charges. The repair work was based on locally available materials and techniques and hence, the programme benefited the businessmen and construction workers in the villages. In general, the villagers of Ranga Reddy district were farm labourers and small-scale businessmen. The average family incomes of most of the villagers were not adequate for maintaining a family of five. Therefore, repair work, though short lived, was an opportunity for them to enjoy additional facilities for their family members. For example, a local painter in Ranga Reddy (West) earned about Rs. 10,000 (£125). He employed five helpers to carry out the work and hence, supported about another twenty-five children and adults for about two weeks.

However, it may be noted that the well-being of a family is not merely the economic improvement only. It requires a variety of socio-cultural factors to determine the well being or satisfactory life in a community (Reddy, 2002). A survey was conducted in all twenty eight sites in Ranga Reddy district by interacting with the construction workers about what they did at home, how they spend money, etc. The survey revealed that, with increase in income, their first priority was to spend money on more food and then on medical facilities, purchase clothes, etc. (Figure 6-7). It is interesting to note that most of these observations tallied with the observations by Reddy (2002), which was found through a participatory poverty assessment study conducted in Indian villages (location not mentioned).

Figure 6-7 The income-multiplier effect.



Source : Author

6.5.3 Database as a Feedback to the Designers, Users and Project Managers

It has been mentioned before that many of the defects were caused by lack of housekeeping. Apart from that there were defects caused by inappropriate detailing and design, faulty workmanship and poor quality materials. The following chart shows the different categories of defects occurred in Andhra Pradesh Primary Education Project.

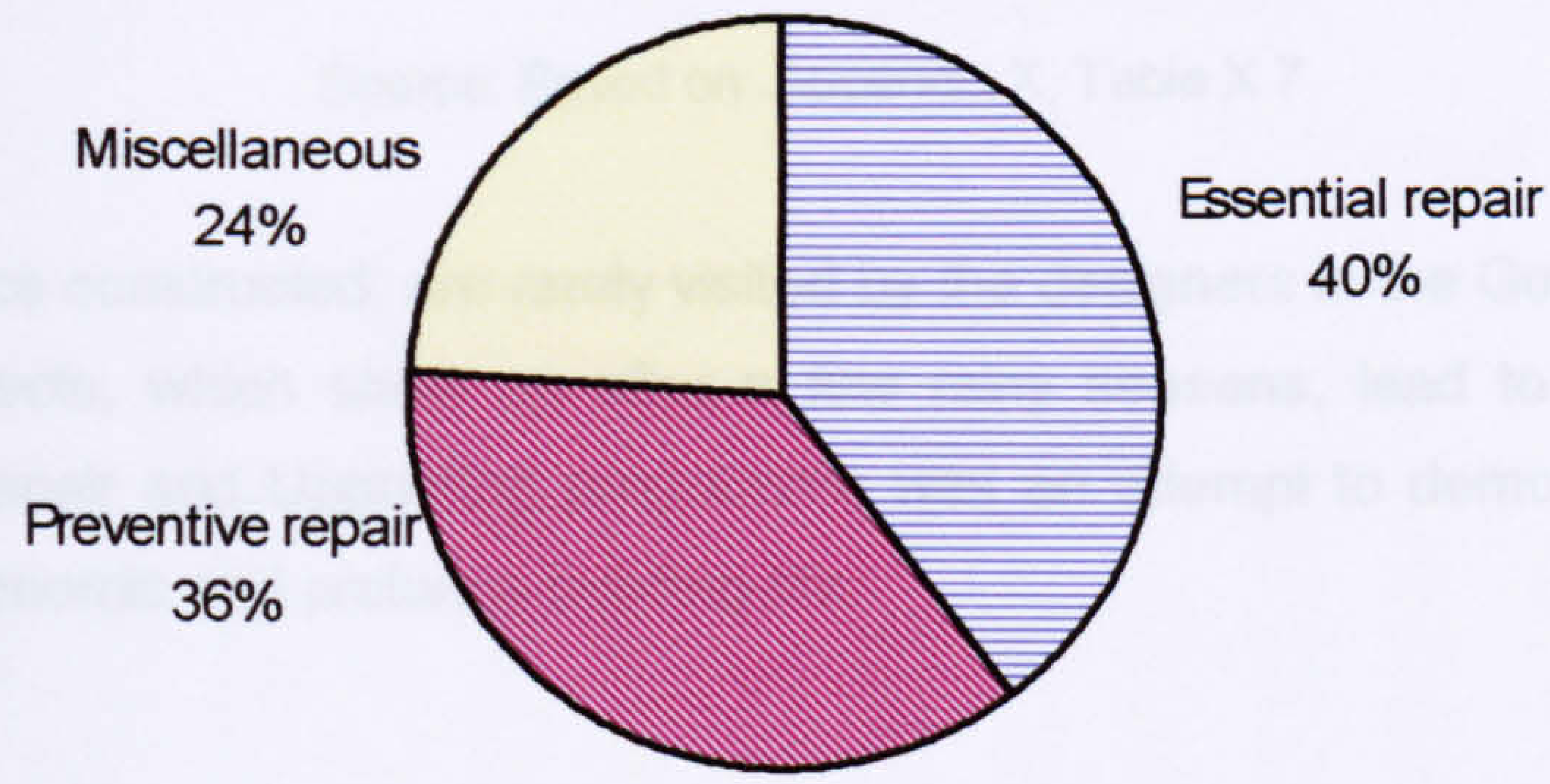
Table 6.1 The frequency (in percentage) of various defects owing to design, materials and workmanship faults in the school buildings at Ranga Reddy.

	Defects owing To	**Out of total number of buildings**	**Frequency of occurrence (%) and actual numbers**
	Design		
D1	Direct sunlight in the classroom	29	28% (8)
D2	Door and window shutters opening inside- unsafe	29	34% (10)
D3	Open verandah- distraction	29	45% (13)
D4	Rainwater penetration- no chujja	29	14% (4))
D5	Rainwater penetration- no roof vent	5	40% (2)
D6	Rainwater penetration- low sill height	29	3% (1)
D7	Cracked cement stabilised mud block (10%)	2	100% (2)
D8	Lintel cracks	29	10% (3)
D9	Roof leakage - through cracks	29	3% (1)
D10	Disturbed roof tiles- wind uplift	6	50% (3)
D11	Eroded cement stabilised mud block (5%)	4	75% (3)
D12	Gable wall cracks	9	67% (6)
D13	Damaged frameless doors and windows	5	100% (5)
D14	Joint crack- ferrocement channel	1	100% (1)
D15	Rainwater - no drip course	29	14% (4)
	Materials		
M1	Defective doors and windows	29	62% (18)
M2	Eroded bricks	18	67% (12)
M3	Eroded cement stabilised mud block (10%)	2	50% (1)
	Workmanship		
W1	Roof leakage – soaking	29	38% (11)
W2	Stone concrete block wall soakage	5	20% (1)

Source: Based on Appendix IX, Table IX.29

As explained in 6.4.3, the types of defects were subdivided into three, viz., 'Essential', 'Preventive' and 'Miscellaneous'. It may be recalled that the "Essential" repairs were owing to faulty design, workmanship and materials, and deteriorate rapidly if not rectified in time. "Miscellaneous" were those interventions, which improved the existing designs of the classrooms. Preventive maintenance is the periodic cleaning, painting, etc. The following is the distribution of these three types of expenditure under the Repair and Upgrading Programme.

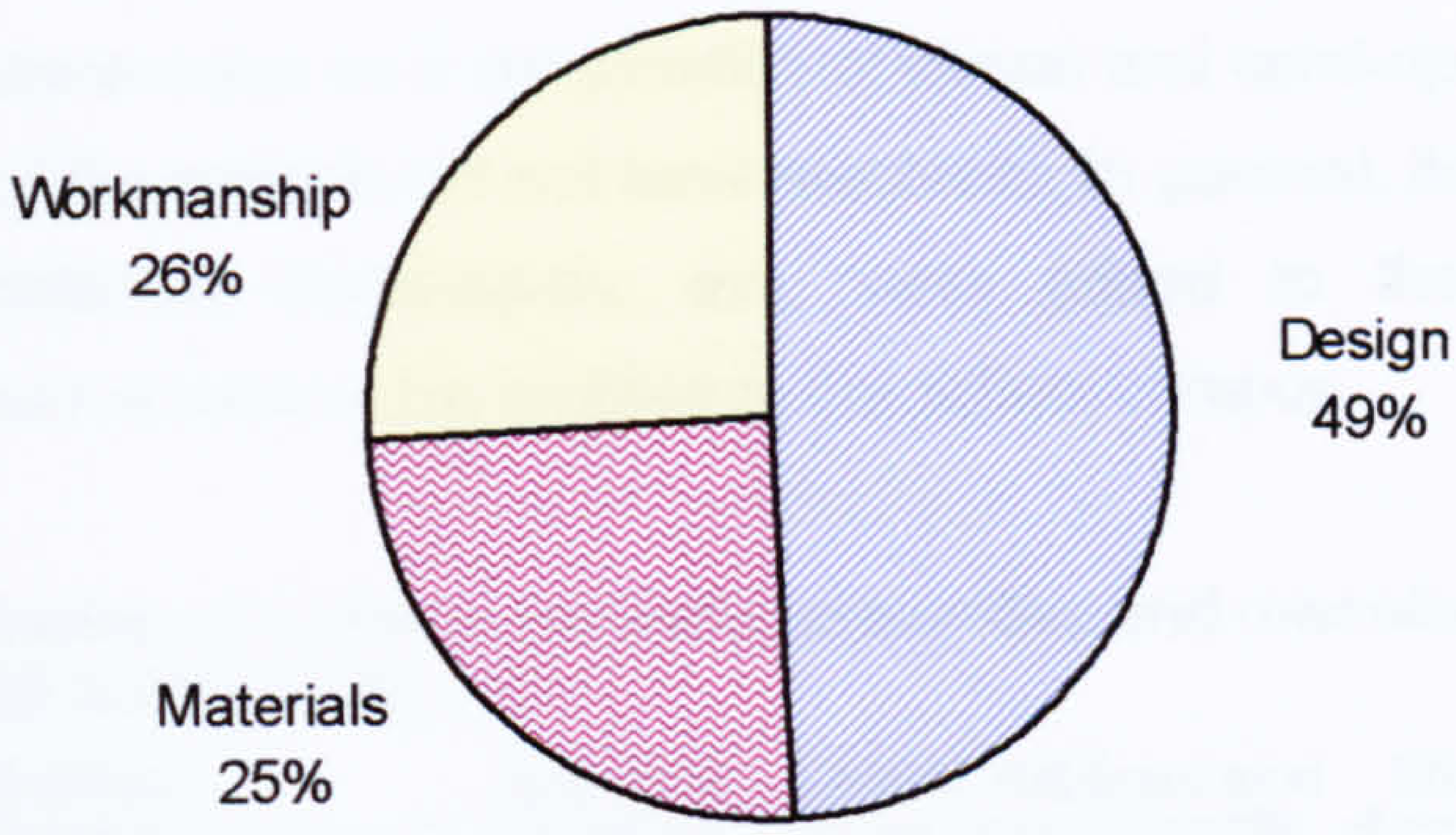
Figure 6-8: The percentage distribution of total cost of repair for correcting different types of defects.



Source: Based on Appendix X, Table X.6

The Figure 6-8 shows that the highest percentage of investment was on the essential repairs. An in-depth investigation on this type of defects revealed that essential repair resulted from faulty workmanship, poor quality materials and faulty design and detailing (shown in Table 6.1). The above Figure 6-9 shows that within the "Essential" repair, 49% of the expenditure was owing to faulty design decisions. Therefore, by referring to the types of defects shown in Table 6.1 at design stage, one could reduce future maintenance costs. Use of faulty materials may be attributed to poor quality control by the engineers. However, in the present context, the eroded bricks were owing to a manufacturing defect, which could not be detected at the time of construction. The brick manufacturers of Ranga Reddy district were informed about the erosion of wire-cut bricks produced by them and, as a consequence, they had appointed a specialist to investigate the matter. The low percentage of workmanship defects indicates that the construction skill was good. This clearly indicates that the technologies could be disseminated.

Figure 6-9 The percentage distribution of total cost of essential repair for correcting workmanship, materials and design-related defects.



Source: Based on Appendix X, Table X.7

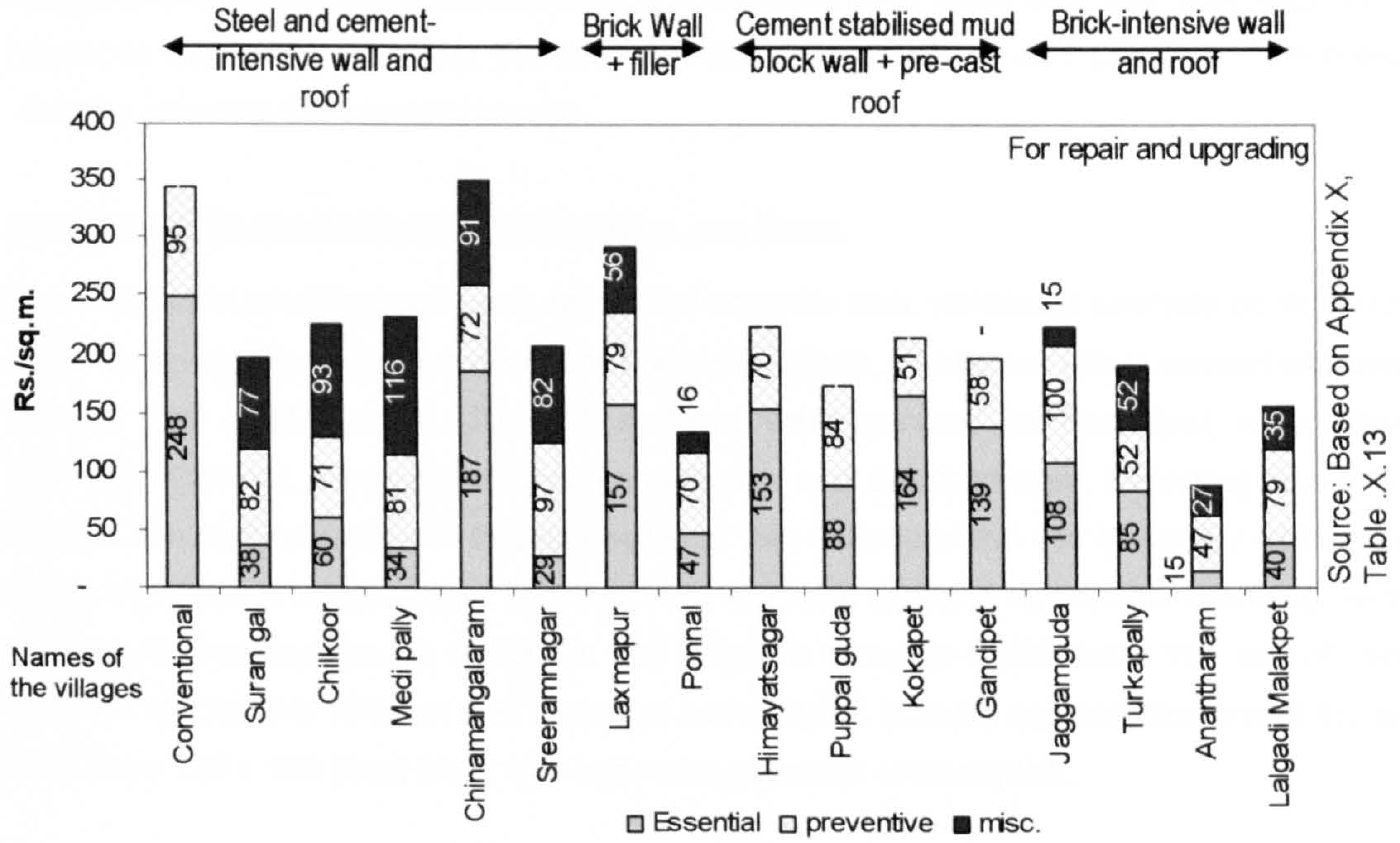
The buildings, once constructed, are rarely visited by the designers in the Government sector and hence, small defects, which show up after a few rainy seasons, lead to major maintenance problems. The Repair and Upgrading programme was an attempt to demonstrate that a timely intervention is economic and prolongs building-life.

6.5.4 Life Cycle Impacts

Figure 6-10 shows the distribution of essential, preventive and miscellaneous intervention costs per square metre of plan area. These expenditures were under the Repair and Upgrading programme undertaken in 1999-2000. Figure 6-10 is based on the data provided in Table X.1, Appendix X, which shows the expenditure under three heads (essential, preventive and miscellaneous) for all the sites in Ranga Reddy district. As with the chapter 5 on new construction of the school buildings in Ranga Reddy, the same sixteen out of twenty nine sites have been considered for life cycle data analysis. The rest were either similar technologies or conventional systems. The data provided in Table X.1, Appendix X have been converted into cost per square metre of plan area. These data were scrutinised and approved by the Panchayatiraj Engineering Department, Government of Andhra Pradesh. It may be noted that the main focus of this section has been on the quantitative aspects of the repair work in Ranga Reddy district. This will help us to assess the life cycle impacts which have been explained in detail in chapter 11.

Let us first analyse the pattern of expenditures on essential, preventive and miscellaneous interventions (1999-2000) in Figure 6-10. In Chilkoor, Chinnamangalaram and Medipally, the miscellaneous costs were high. At Chinnamangalaram, construction of a circular podium for the children to sit under a tree was a value addition to the school environment. In Medipally, the School Committee members constructed screen walls to convert veranda-classrooms into closed spaces. This was done since the community wanted to stop people from playing cards in the semi-open classrooms after the class hours and on holidays. However, this went against the main objective of planning classrooms as a combination of closed and semi-open spaces for comfort in summer, since most of the schools did not have electricity. In general, items such as painting on walls, gardening, additional chalkboards, etc., were added to the existing school. The communities were proud of such value addition to the school campus.

Figure 6-10 The distribution of costs on essential, preventive and miscellaneous Repair and Upgrading works (1999-2000). Rs80 = £1.



Some of the schools carried out extensive artwork in the classrooms and had made visual campaign for community awareness on health, hygiene and general education. There was no expenditure on miscellaneous items at Kismatpur (conventional) Puppalguda, Kokapet, Gandipet, Himayatsagar etc., as shown in Figure 6-10. The miscellaneous expenditure was an indicator of community awareness and involvement in the programme. Appendix IX shows a list of items adopted by the communities for the enhancement of school-environment, which will act as guidelines for the architects engaged in school design.

The expenditure on preventive maintenance depended on both design and technology. For example, the least preventive maintenance at Anatharam was owing to its low wall height of 1800 mm with corbelled brick arch roof, which varied between 2100 mm to 3000 mm for the other technologies. Thus the internal plastering and painting cost at Anantharam was low. Apart from that the underside of the corbel brick arch roof had cement pointing and hence, there as no expenditure on ceiling painting. All these factors contributed to make the preventive maintenance cost at Anantharam the minimum (Rs.47, i.e. £0.59 per square metre) as shown in Figure 6-10. The preventive maintenance cost at Turkapally (Rs.52, i.e., £0.65 per square metre) was close to Anantharam for similar reasons. The variations in preventive maintenance costs in Figure 6-10 were owing to the area of painting depending upon wall height, requirement of ceiling painting, requirement of plastering and painting on external face of the walls, etc. Let us now look at the expenditures on essential repairs shown in Figure 6-10 under the Reapir and Upgrading programme in 1999-2000. The technologies adopted in Ranga Reddy have been broadly categorised into steel and cement-intensive wall and roof, brick wall and filler slab, cement stabilised mud block wall and pre-cast roof and brick-intensive wall and roof. The following sections analyses the essential repairs.

GROUP 1 - STEEL AND CEMENT-INTENSIVE WALL AND ROOF.

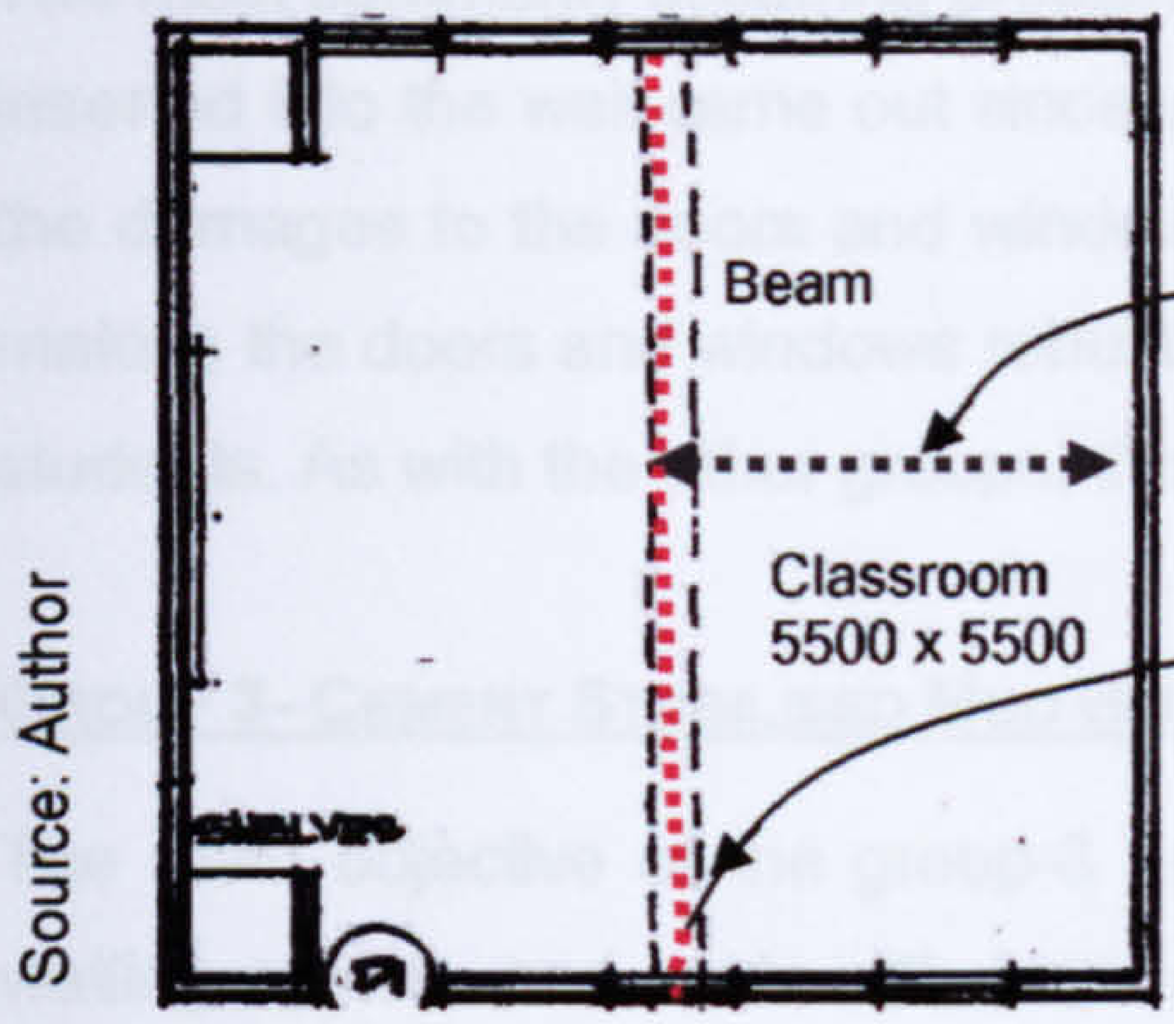
Stone concrete block masonry wall, reinforced concrete slab, reinforced concrete plank and joist, reinforced concrete channel roofing are under this group. These are either cement-intensive or cement and steel-intensive. Group-1 systems were adopted at Kismatpur (conventional), Surangal, Chilkoor, Medipally, Chinnamangalaram, and Sreeramnagar. Excepting conventional system, the main objective of Group-1 systems was to reduce the use of energy intensive and costly materials in construction. This has been done by adopting form-active spanning systems such as channel section, in which the self weight is reduced significantly. The use of cement concrete blocks with 190 mm wall thickness had reduced material consumption and at the same time 290 x 190 x 100 (mm) block size had reduced mortar consumption.

There was no defect in the foundation, which was load bearing coursed rubble stone masonry in 1:6 cement sand mortar. Stone concrete blocks had developed seepage problems in Surangal and Sreeramnagar owing to lack of quality control. Other than this, the performance of the block masonry was good.

Most of the classrooms in Andhra Pradesh Primary Education Project were 5.5 metres wide. As the economic spans of the pre-cast roofing systems are around 3.6 metres, a beam was introduced in the classroom as an intermediate support to reduce the spans. This had also reduced self-weight of the pre-cast elements which made manually operated erection easy. The most important aspect of this type of system is to consider the inevitable thermal movements of the pre-cast components while doing the architectural detailing at roof level. This was not done at places such as Chinnamangalaram.

In January 2000, it was noticed that thermal movements caused cracks at the joints (in Chinnamangalaram, etc.) where two pre-cast components were supported on the intermediate beam. Since linear expansion of the pre-cast units along spans was more than in the lateral direction, a crack developed in the top screed of the roof along the length of the supporting beam (Figure 6-11). This may be attributed to a design mistake since the designer should have considered this type of movement while detailing the roof. The high cost of essential repair at Chinnamangalaram shown in Figure 6-10 was owing to these reasons. The crack caused minor water seepage but there was no threat on the structural safety of the roof. The essential repair cost of the conventional roof was high owing to the repair of the waterproofing treatment.

Figure 6-11 : Plan of a classroom showing the central reinforced cement concrete beam acting as a support to the pre-cast elements.



The essential repair at Chilkoor enhanced the classroom environment. Keeping the openings too high in the semi-open classrooms was a design mistake that allowed rain to come in and hence, it was corrected. Stone concrete blocks were used to reduce the openings to the required size at Chilkoor.

Inadequate seasoning of the local timber in doors and windows led to geometrical deformation. The most commonly occurring defect was the damaged hinges and tower bolts, which could be attributed to the students' habit of playing with the shutters. These were repaired at Kismatpur (conventional), Chilkoor, Chinnamangalaram, Surangal and Sreeramnagar. Apart from that, vandalism by the villagers in a few places caused damage to the doors and windows. The paint on doors and windows were in just acceptable condition and hence, it was the right time to carry out the repainting exercise to prevent deterioration of the physical conditions. The Tandur stone flooring was in very good condition and turned out to be almost "preventive" or "corrective" maintenance-free. The white wash on the interior surfaces were in acceptable condition. However, as a preventive action, all the interiors were painted.

GROUP 2- BRICK WALL AND FILLER SLAB ROOF

This group reduced the consumption of brick and cement by adopting rat-trap bonded wall. The cement and steel consumptions were reduced by using reinforced cement concrete filler slab roofs, which was lighter than reinforced cement concrete slab. The walling system performed well over time, except erosion of some bricks, which was owing to a manufacturing defect. Minor repair of the pointing was also done. The roof performed reasonably well, except in Luxmapur where poor workmanship caused soakage. The technical support group, who promoted this technology, introduced flat arches made of bricks in openings for the doors and windows. In almost all the places, the flat arch cracked owing to settlement of the buildings, which was up to a maximum of 50 mm.

The most commonly occurring problem was the frameless doors and windows. The wooden plugs inserted into the wall came out since wind stays were not provided. The students caused most of the damages to the doors and windows by playing with them. It appears that there is a need for making the doors and windows robust enough to take the additional wear and tear caused by the students. As with the other groups, the condition of painting was in acceptable condition.

GROUP 3- CEMENT STABILISED MUD BLOCK WALL AND PRE-CAST ROOFS

The main objective of the group-3 technologies was to adopt cement stabilised mud block as walling system and roofs with ferrocement channel, jack-arch, micro-concrete tile, stone, etc., where the consumption of cement and steel were lower than reinforced cement concrete. The group-3 technologies were adopted at Himayatsagar, Puppalguda, Kokapet and Gandipet.

There was no defect in the foundation, which was load bearing coursed rubble stone masonry in 1:6 cement sand mortar. Stabilised mud block masonry wall with five percent cement stabilisation was used at Puppalguda, Kokapet and Gandipet except Himayatsagar, where ten percent cement stabilisation was used. Ferrocement channel roofing was used at Himayatsagar. Micro-concrete tile roofing and jack-arch was used at Puppalguda and Kokapet. Stone slab roofing on precast reinforced concrete joists was used at Gandipet. All these technologies have been explained in Appendix III and IV.

Erosion of cement stabilised mud block was a major problem at Gandipet, Chandanagar, Kokapet and Puppalguda. This need not necessarily be viewed negatively while evaluating performance of this technology. Every material has its own limitations and the solution lies in designing around its weakness. For example, cement stabilised mud block should be sheltered, as far as possible, from direct rain water at roof and plinth levels. In Gandipet, high unprotected walls accelerated the erosion of the cement stabilised mud blocks. High cost of essential repairs at Himayatsagar, Kokapet and Gandipet (Figure 6-10) may be attributed to these reasons. Groove pointing of the masonry added to the problem of erosion by exposing more surface area to the rains.

There were other important observations on the performance of cement stabilised mud block. In some of the schools, it was noticed that the children, while playing, run around the building with their fingers touching the walls continuously. This had damaged corners as shown in the photograph (Figure 6-12). Similarly in Kokapet lack of corner protection created water stain and also seepage. Loss of chunks of materials was observed at Kokapet that may be attributed to lack of quality control during block making.

Figure 6-12 Showing wall corners damaged at Gandipet owing to handling by the pupils

Source: Author

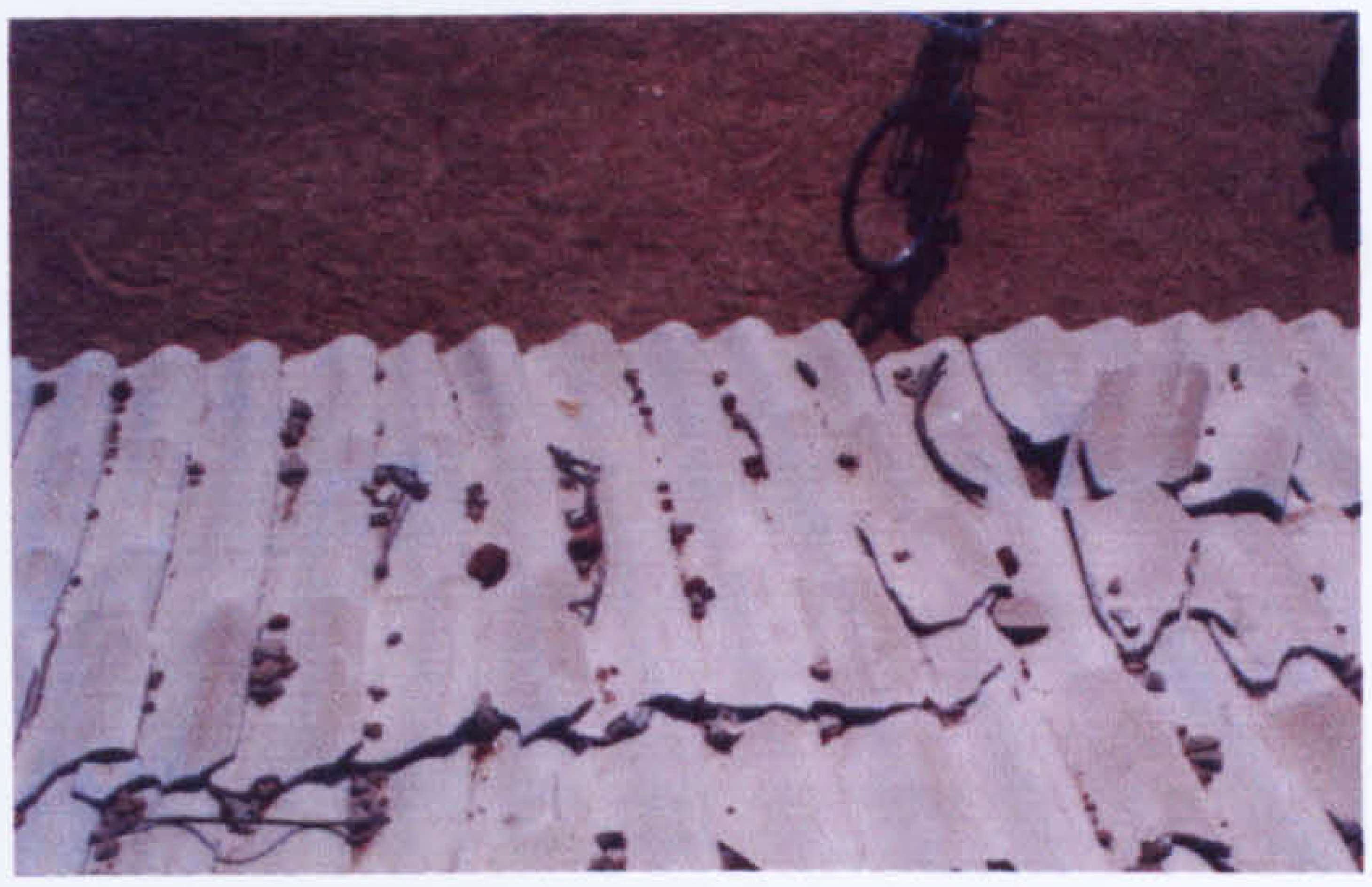
Source: Author

Figure 6-13 Showing stain on wall owing to the absence of a drip course at joist-ends

The roofs adopted under this category were Jack-arch and sand stone roofing on pre-cast joists, micro-concrete tile roofing on steel under-structure and timber purlins. Let us look at the technologies one by one. jack-arch roofing had performed well. However, at Puppalguda seepage through the waterproofing plaster was observed. The absence of a drip course at pre-cast joist-ends in Puppalguda had created black stains on the wall (Figure 6-13). The Sand stone roofing, in general, did not have any major problem.

Micro concrete tile roofing did not have major complaint. However, at Puppalguda the students pelted them with stones for fun, which broke the tiles (Figure 6-14). The villagers sited this as the inability of the roof to withstand the impact of stone. Although the damaged tiles were replaced, the headmaster was reminded that the teachers should discipline their students so that they do not destroy their own school.

Figure 6-14 Damaged micro concrete tiles at Puppalguda, caused by the students' habit of pelting them with stones.



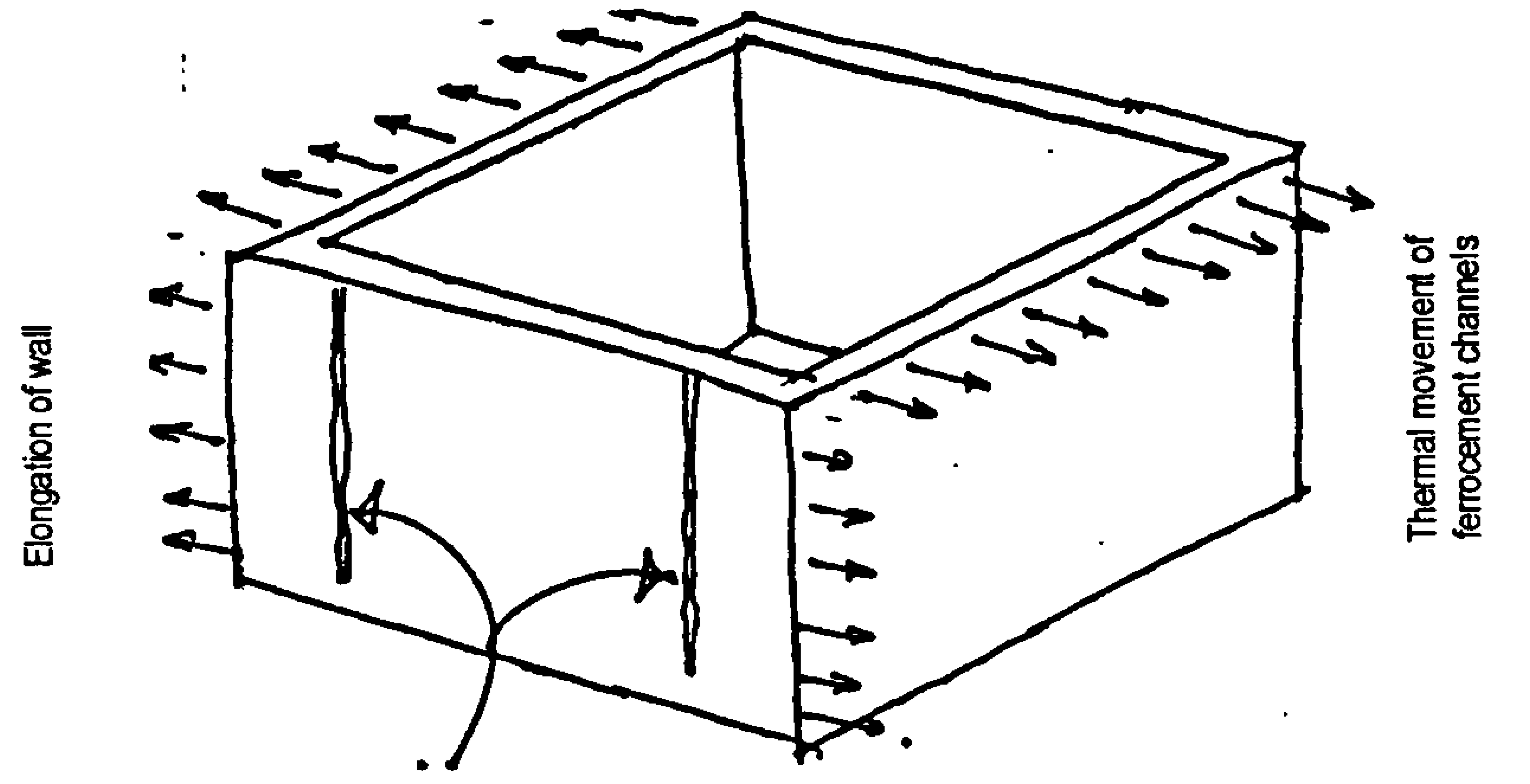
Source: Author

Figure 6-15 Thermal cracks in pre-cast ferrocement channels facing west at Himayatsagar

Source: Author

Ferrocement channel at Himayatsagar had posed a problem owing to the thermal expansion of the channels. In addition to this, the wall facing West was subjected to intense solar radiation in summer leading to thermal expansion. The 150 mm thick walls could not bear the tensile stresses and hence, the walls had a mild vertical crack, which has been explained in Figure 6-16. This was not observed on the Eastern wall.

Figure 6-16 The cracks developed owing to the thermal expansion of the ferrocement channels and the west facing wall at Himayatsagar.



Source: Author

Owing to mishandling by the students and also because of the poor quality of materials, doors and windows were damaged and had to be repaired at Kokapet, Gandipet and Puppalguda. As observed in other groups, the condition of the paints on doors, windows, walls, etc., were in acceptable conditions.

<u>GROUP 4- BRICK-INTENSIVE WALL AND ROOF</u>

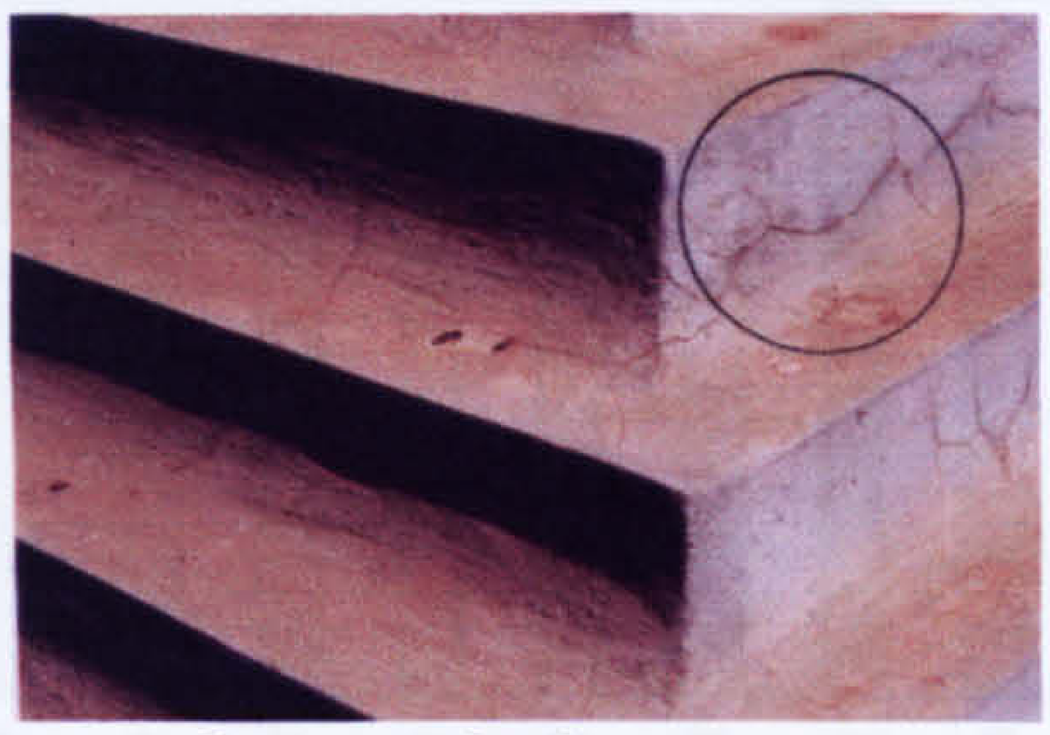
The main objective of this system was to maximise the use of locally available bricks, which was supportive to income generation. To lower cost, the consumption of brick was reduced by adopting rat-trap bonded wall and pyramid roof, in which, wall height required was 2.1 metres compared to 3 metres in case of flat roofs. Group-4 technologies were adopted at Turkapally, Jaggamguda, Lalgadimalakpet, Anantharam.

Coursed rubble stone masonry in cement mortar was used in the foundation and there was no defect owing to differential settlement of foundation. Rat-trap bonded brick-masonry wall was used in all the buildings under this group except Turkapally, where a combination of 115 mm brick wall and 230 mm solid bricks wall was constructed. Rat-trap bond is explained in Appendix III. Brick pyramid was used at Majeedpur, Turkapally, Lalgadimalakpet and Jaggamguda. Corbelled brick arch roofing was used at Anantharam and hybrid slab was used at Muduchinthalapally. All these technologies are explained in Appendix III and IV.

The rat-trap bonded wall did not have any major problem, excepting that some bricks at Turkapally and Jaggamguda were eroded owing to manufacturing defects. When the brickfield owners were contacted in this regard, they informed us that they had also received complaints from the users and had rectified the production process accordingly. The eroded bricks were chiselled off and new bricks were placed in position with cement mortar.

There were four corbelled brick pyramids at Turkapally. One out of the three had soakage problem, which may be attributed to surface cracks owing to insufficient curing. The second one had soakage at one of its edges. The rest of the pyramids had performed well and therefore, it appeared that the technology could be durable. However, the community was insistent that the entire roof must be treated and hence, the cost of essential repair went up. This had increased the cost of essential repair as shown in Figure 6-10.

Figure 6-17 Thermal cracks on the waterproofing plaster on corbelled brick pyramid at Majeedpur



Source: Author

As observed at most of the sites under Andhra Pradesh Primary Education Project, the doors and windows were damaged by the students. The worst situation was at Jaggamguda. The hinges, tower bolts and window stays were damaged. Considering the situation, it may be suggested that the door and window and door fixtures should be designed by assuming that two students will be hanging from the handles and top of the shutter. The conditions of the paints on doors, windows, walls, etc., were acceptable.

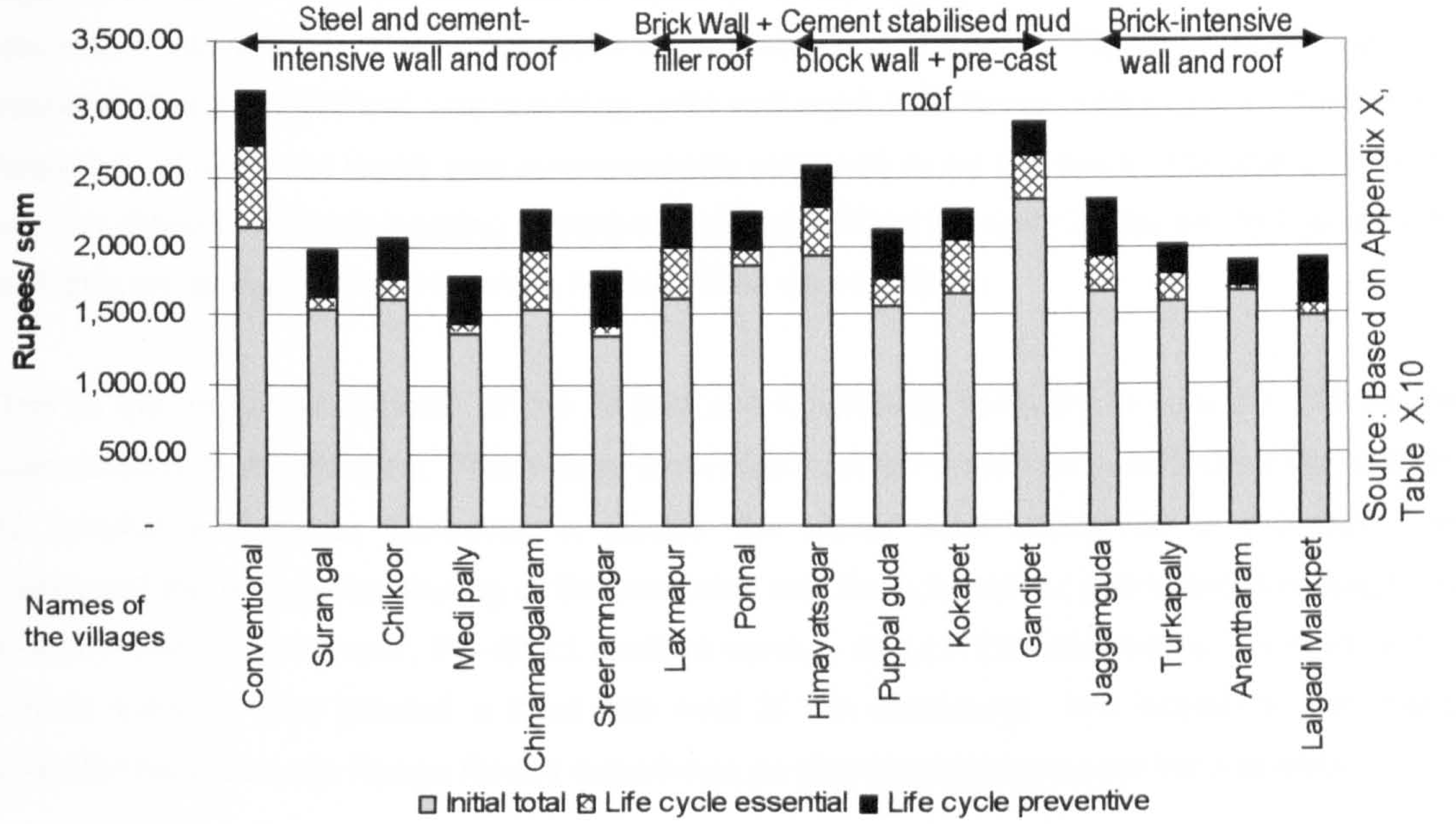
The semi-open veranda as classrooms at Turkapally used to cause distraction of the pupils and to solve this problem, the School Committee had built a 1500 mm high wall. Funding was raised from the community, which was an excellent example of ownership and enthusiasm.

Let us now look at the life cycle costs based on the essential and preventive interventions shown in Figure 6-10. It may be noted that the miscellaneous expenditure is unlikely to occur repeatedly in a building life. Therefore, only the life cycle implications of the essential and preventive maintenance have been considered in Figure 6-18 based on the following.

- Discount rate has been assumed to be at the rate of 13%, which was the fixed deposit interest rate (more than 2 years) offered by the United Bank of India (UBI, 1996). It is 8% in 2006 (UBI, 2006)

* Inflation at the rate of 8% for the period 1995-96 (ICRIER, 2003-2004). Based on annual price index from the Economic Survey, GOI (2001-2002:110) and GOI (2003-2004: 87). The inflation rate in 2006 is 5.5% (RBI, 2006).
* All the costs have been recalculated in 1996 rates, which are in Appendix X.
* Life span of the school buildings 50 years (IS 875, 1987).

Figure 6-18 Life cycle essential and preventive repair costs of the four groups of technologies. Rs80 =£1.



It has been mentioned in chapter 5, that the designs adopted at different sites were different. The plinth heights at different sites, with respect to the near-by roads, were also different. Therefore, this chapter will analyse the village-specific life cycle impacts of construction technologies, designs and plinth heights on socio-economy and environment per unit plan area of the schools in Ranga Reddy district. In chapter 11 on life cycle impact assessment, a classroom of 5.5m x 5.5m internal dimensions and uniform plinth height have been assumed to compare the socio-economic and environmental impacts of the construction technologies. Figure 6-18 shows the pattern of essential and preventive maintenance costs of various technologies adopted in the schools in Ranga Reddy district. The initial unit cost of construction has also been presented in the graph for comparison. Figure 6-18 shows that steel and cement-intensive technologies had more life cycle preventive maintenance cost than essential at Surangal, Chilkoor, Medipally. For conventional and Chinnamangalaram, the life cycle essential maintenance is higher than the preventive. The cement stabilised mud block walls with pre-cast roofs at Himaysagar and Gandipet had more or less equal expenditure on preventive and essential maintenance. The brick-intensive systems at Jaggamguda and Turkapally were also similar to Himayatsagar and

Gandipet. Life cycle essential repair costs were low at Medipally, Sreeramnagar, Anantharam and Lalgadimalakpet.

LIFE CYCLE SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS

Four years after the schools under Andhra Pradesh Primary Education project were constructed; an intervention took place in 2000. As mentioned before, the cost of intervention has been categorised into "Essential", "Preventive" and "Miscellaneous". The essential cost had the urgency of repair; however, such interventions were not likely to be required as frequently as the preventive intervention. The water roofer's other works in Ranga Reddy were inspected. It was observed that his treatment was surviving quite well even after ten to twelve years. Therefore, the frequency of essential repair was conservatively assumed to be ten years. The author interacted with the Government engineering department of Delhi, West Bengal, Orissa etc. to find out if they had data on similar issues. However, no such data was available.

One of the important aspects of the Repair and Upgrading programme was the communities' interventions in the designs. There were examples of open verandas provided by the architects for comfort in summer. However, in places, the winter wind, distraction of the pupils, etc., hampered the normal functioning of the verandas and the community had raised low-height walls to solve both. In Kesavpur, the direct sunlight used to disturb the classrooms. As a solution the school teachers had planted a local tree next to the classroom. The architects can make a checklist based on the Ranga Reddy experience so that they do not repeat the mistakes.

The existing physical conditions of the plaster, painting, etc., in the schools were acceptable. However, some defect as peeling off and discolouration of paints, damaged door hinges, flooring, etc., were noticed. By the time the physical repair started, most of the buildings were a little more than four years' old and it was just about the right time for a preventive maintenance in form of painting and minor repairs. An interaction with the local people revealed that they paint their houses after every three to five years. There were many such houses in the villages of Ranga Reddy of age varying between 75-100 years. The painting contractors in several villages reported that a building should ideally be painted after every three years. However, they opined that it can be stretched up to four years considering the low rainfall rate in Ranga Reddy. Considering these, it may be reasonable to assume the frequency of preventive maintenance as four years.

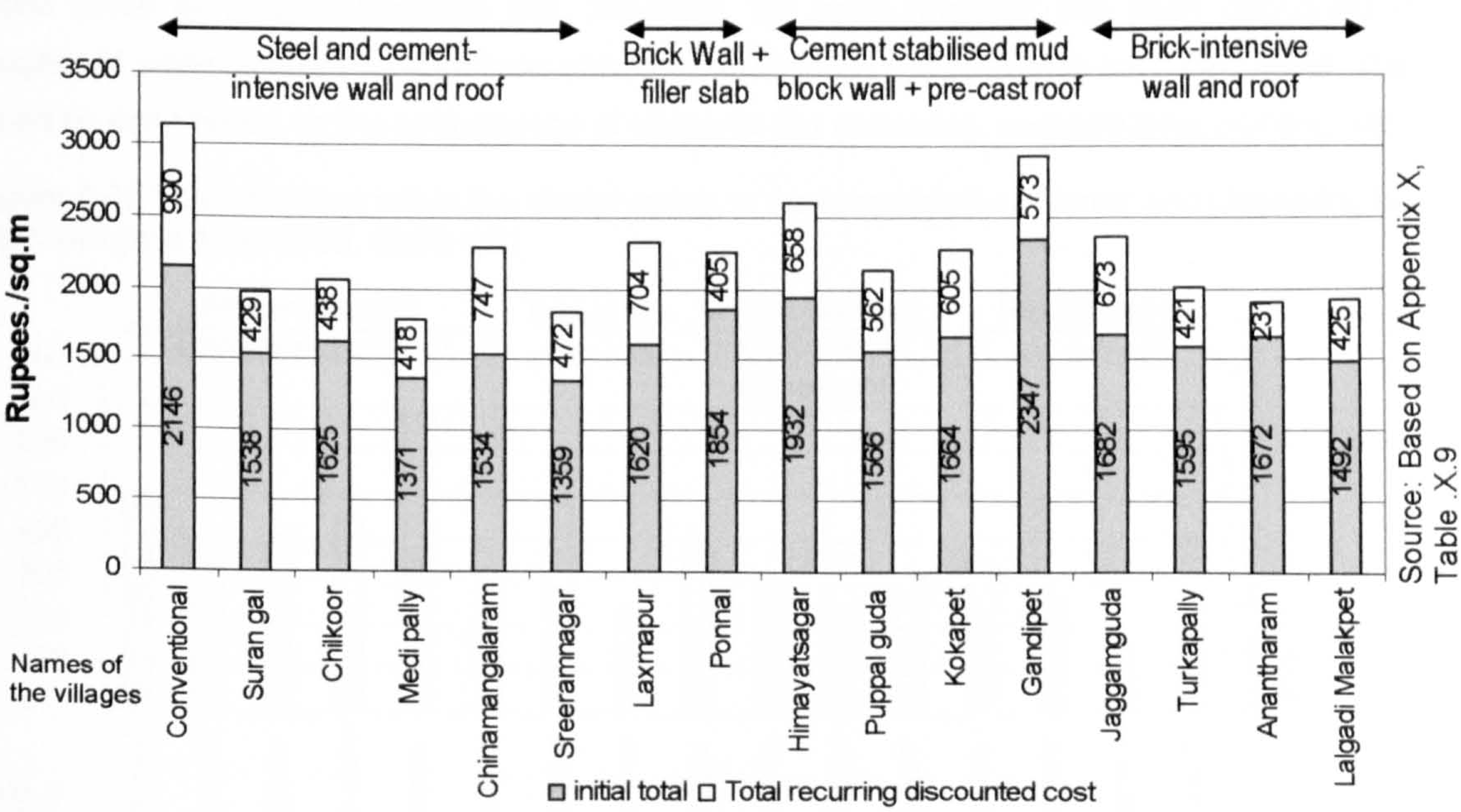
The repair costs of May, 2000 were recast by adopting 1995-96 rates to calculate the percentage of essential, preventive and miscellaneous items with respect to the actual project investment. It may be noted that the major essential repair was waterproofing of the roof, which has been a problem for many years in the building industry. While implementing the Repair and Upgrading programme, many Government buildings were found to have leaking roofs, which rapidly reduced their durability. The Panchayatiraj engineers reported that, according to their experience, a corrective maintenance after every ten years is required for the school buildings. However, they can not do that because of fund shortage. Therefore, in this context, a discounted cost of the essential repair works have been calculated with a frequency of ten years.

Miscellaneous costs were not considered while calculating the life cycle impact assessment. The main reason is that, while some communities were conscious and hence, spent money on design enhancement, the others did not consider that to be important. Therefore, although this is an important aspect, non-uniformity was the main reason for not considering it.

The following figure shows the life cycle impacts of the buildings at different sites, which were built by adopting different construction technologies in 1995-96. The Figure 6-19 indicates that there is a significant variation in life cycle recurring cost of different technologies and different architectural designs. Therefore, it will be more meaningful to compare whole life costs of the different components of the buildings, i.e., the wall and roof. Since no defect was found in foundation, it has been kept out of the calculations.

Unit cost

Figure 6-19 The life cycle costs of the school building in Ranga Reddy district.Rs80 = £1.



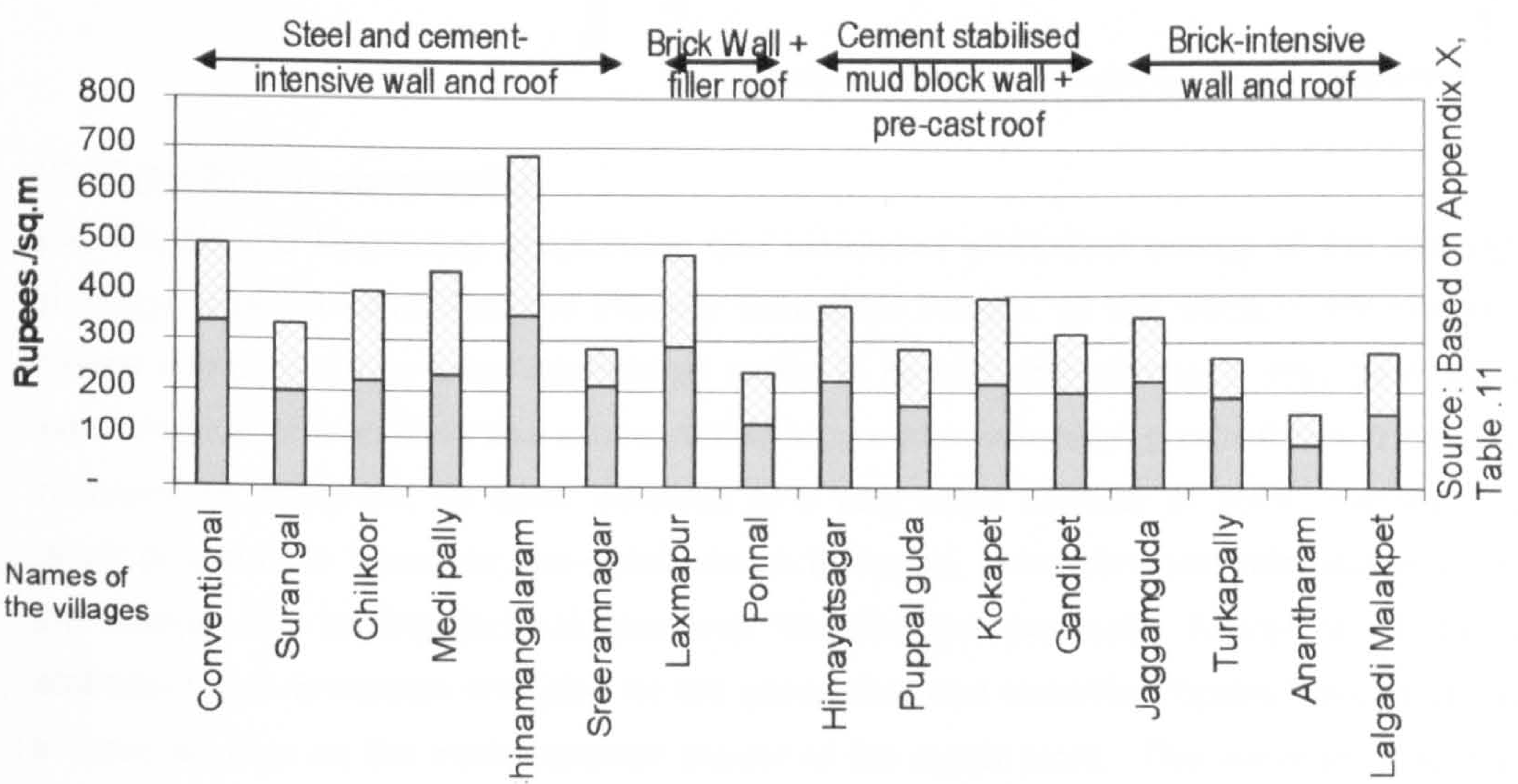
The life cycle costs have been shown in Appendix X. The process of calculation is shown in File-3 of Figure 1.7. The life cycle costs of the schools in Ranga Reddy district have been shown in

Figure 6-19. The main reason for high life cycle cost of conventional system was the repair of roof water proofing and repairs of wall plaster (Rs.990, i.e., £12.4 per square metre). One of the reasons for high life cycle cost at Chinnamangalaram was the correction of the thermal cracks at roof (Rs.747, i.e., £9.33 per square metre). The least discounted-recurring cost was at Anatharam (Rs.231, i.e., £2.9 per square metre) with a corbelled arch roof. The 1:4 cement sand mortar with cement slurry paint as waterproofing worked well and did not develop any significant crack or soakage in the roof. An inspection in December, 2003 revealed that the roof at Anantharam, even after 8 years, was in good condition. The high discounted-recurring costs at Luxmapur, was owing to the defects in the roofs already explained under the group-2 technology. Figure 6-19 shows that, on the whole the recurring costs of most of the schools were less than half of the new construction costs.

Retention

Figure 6-20 shows that the total retention of money out of the investment on Repair and Upgrading programme in 1999-2000, was very significant, except at Kismatpur (conventional) Turkapally and Sreeramnagar. The cement and Sailo-xe-crete, a polymer-based paint, was used at these three sites for water proofing and underside treatment of the filler slab. This was the main cause of most of the money going out of the district. The life cycle retentions owing to essential, preventive and miscellaneous could not be shown separately in this discussion. Such divisions could not be made during data collection per site since there were about thirty to forty repair items at each construction site. However, life cycle retention has been calculated in chapter 11 while different combinations of walling and roofing systems have been calculated. This could be done based on the performance of elements like plastering, waterproofing, painting, etc.

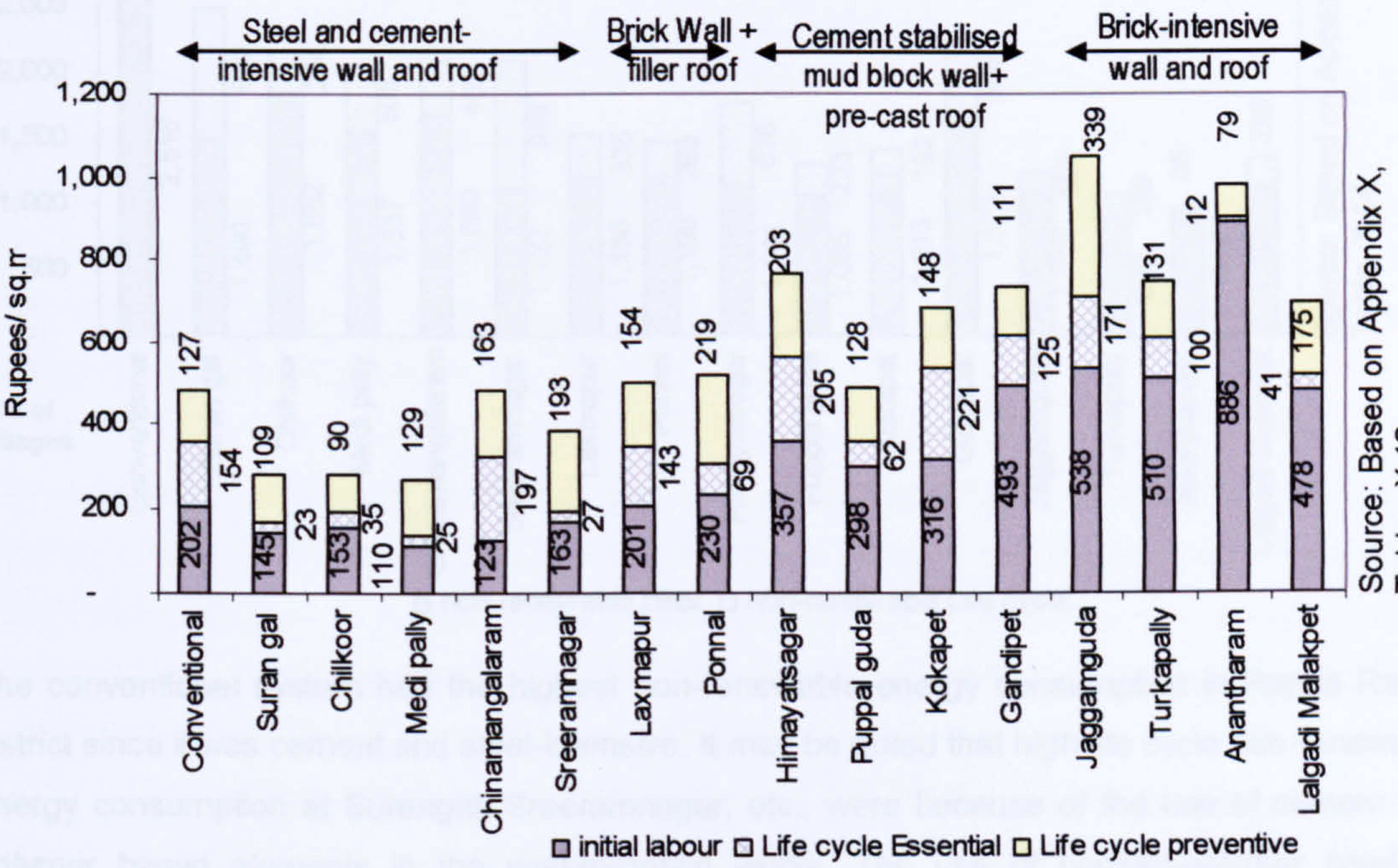
Figure 6-20 The retentions within the district owing to the investment on Repair and Upgrading in each village in 1999-2000. Rs80 = £1



Income generation for construction workers.

Let us now examine the employment opportunities created by the Repair and Upgrading programme in 1999-2000. Figure 6-21 shows that Jaggamguda, Kokapet, Himayatsagar, Chinnamangalaram, Luxmapur, etc., had created high employment opportunities compared to that of the initial construction. On the whole, it may be said that the life cycle implications of different construction technologies on local employment could be substantial as evident in the Figure 6-21. It may, therefore, be important to review this aspect while selecting technologies for a particular social infrastructure development programme, where unemployment problem is crucial. Figure 6-21 shows that Anantharam had the least employment generating technologies. At Chinnamangalaram the life cycle employment is about three times of its initial labour.

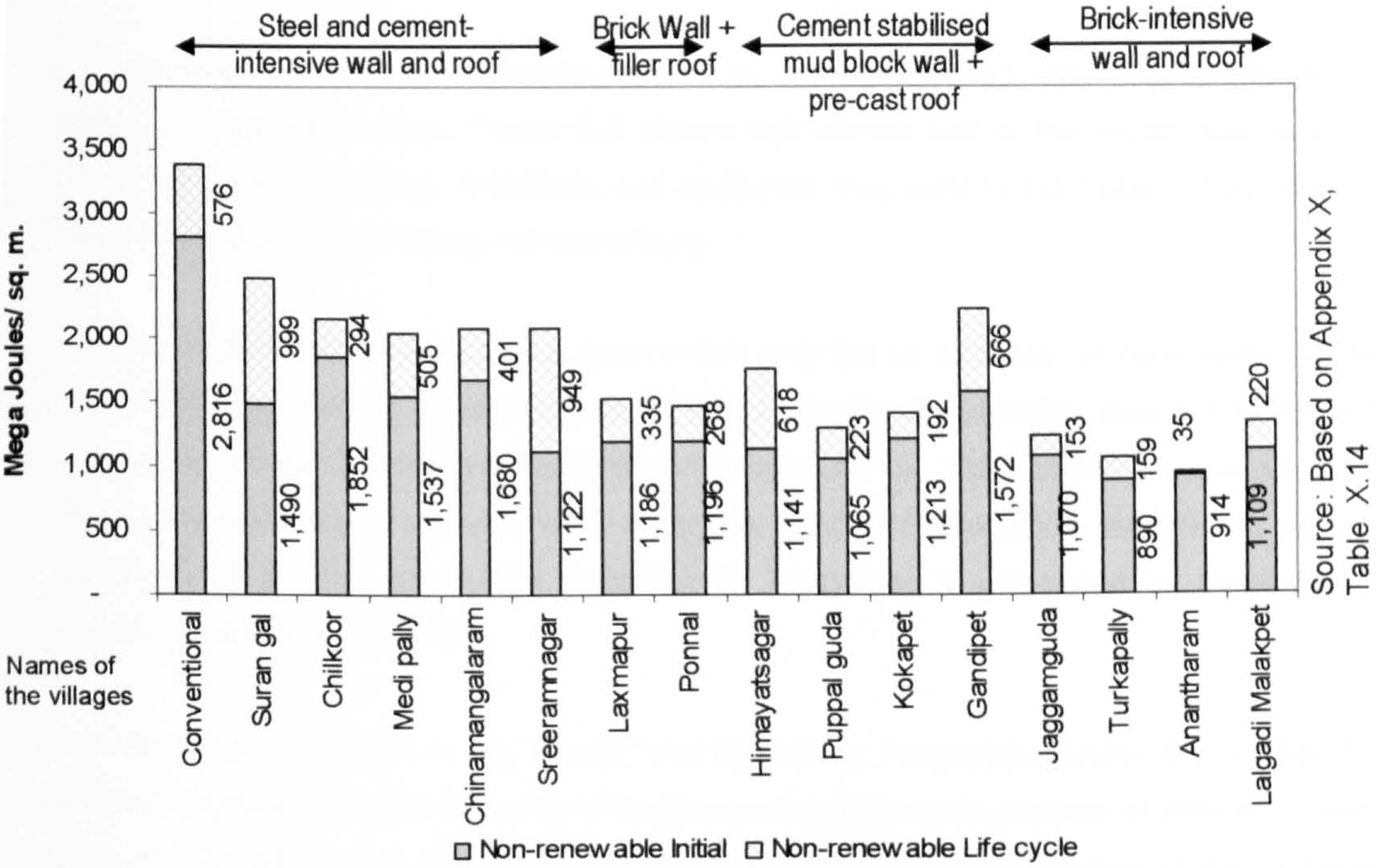
Figure 6-21 The life cycle livelihood opportunities for the construction workers. Rs80 = £1.



Life Cycle Energy consumption

The Repair and Upgrading programme had increased embodied energy of the existing school buildings under Andhra Pradesh Primary Education Project. In this section, the non-renewable energy component has been considered owing to its high importance. It may be noted that the exact division of embodied non-renewable energy under essential, preventive and miscellaneous interventions could not be done because of a very large number of items involved under the repair programme. However, the database on essential, preventive and miscellaneous repair for the walling and roofing technologies was documented precisely. Therefore, in this section, embodied non-renewable energies for the preventive and essential repairs have been combined to have an idea on the environmental impact of the repair work. The average of four years for preventive repair and ten years for essential repair, i.e., seven years, has been assumed for calculating the life cycle embodied energy, which is shown in Figure 6-22. It may be noted that data on embodied non-renewable, renewable and waste energies have been calculated in chapter 9 for the walling and roofing systems, which will be used in the chapter 11 on life cycle analysis.

Figure 6-22 The initial and life cycle embodied non-renewable energies.



The conventional system had the highest non-renewable energy consumption in Ranga Reddy district since it was cement and steel-intensive. It may be noted that high life cycle non-renewable energy consumption at Surangal, Sreeramnagar, etc., were because of the use of cement and polymer based elements in the waterproofing works. The use of cement-polymer paint on ferrocement channels increased non-renewable energy at Himayatsagar. It may be noted that the doors and windows were stolen at Surangal. These were replaced with steel doors and windows to lower the cost and also to avoid termite problems. The use of steel had increased the non-renewable energy consumption at Surangal. The brick-intensive buildings at Turkapally, Anantharam, Jaggamguda, etc., had low life cycle embodied non-renewable energy because rice husk was used for brick burning in Ranga Reddy district.

SUMMARY OF FINDINGS

The life cycle impacts of various construction technologies on maintenance cost, labour intensity and embodied energy had wide variations. There is a significant employment generation potential from repair. The steel and cement-intensive technologies had lower expenditure on essential intervention than preventive maintenance. The high life cycle non-renewable energy consumption of repair at a few places may be attributed to the cement and steel intensive interventions.

The financial burden on maintenance can be greatly reduced with appropriate design and detailing at planning stage. Figure 6-9 shows that almost half of the repair cost was owing to faulty design and detailing. Architects and engineers may refer to the Table 6.1 as a checklist to avoid the design and detailing-related defects.

The expenditure on miscellaneous intervention may be an indicator of community involvement and awareness. Raising a small amount of funds from the communities may not be difficult since villagers in Ranga Reddy have the tradition of paying for the Vidya volunteers (para teachers). In a school like Kesavpur, the community raises Rs.1200 (£15) per month towards the salary of two additional para teachers (Vidya volunteers). Therefore, if ownership is developed, timely maintenance will be possible.

The database generated in the Repair and Upgrading Programme under the Andhra Pradesh Primary Education Project is a step towards assessing life cycle impacts of different construction technologies adopted in Ranga Reddy district. A rapid visual inspection of the buildings was conducted by the author in December, 2003 to examine the conditions of the buildings ever since it was repaired in 2000. It may be noted that it was a visual inspection only and there was no formal documentation. This visual inspection revealed that the assumptions of four and ten years for the preventive and corrective repair appear to be reasonable. However, one more investigation is required to ascertain the frequency of corrective maintenance. The major strength of the database on repair is that the buildings in Ranga Reddy district were constructed under the same level of quality control and are ageing under the same geo-climatic and social setting. Therefore, it is like a laboratory and a constant monitoring on the performance of the buildings will strengthen the database on their life cycle impacts. In the later part of this dissertation, this database has been adopted to forecast life cycle impacts of the different construction technologies.

CHAPTER 7 IMPACT ASSESSMENT: MODEL

7.1. BACKGROUND:

Chapter 5 and 6 demonstrate the impact of different construction technologies on socio-economic and environmental aspects in the Ranga Reddy district of Andhra Pradesh. The analysis showed such impacts in two stages, i.e., for new building construction and its maintenance. Chapter 5 demonstrated the impacts of new construction of school buildings (constructed in 1995-96) based on different plan forms and technologies. Chapter 5 shows the extent of impact on society, economy and environment (embodied energy and CO_2 only), caused by maintenance of the same buildings after about four years (2000) when they were revisited, evaluated and necessary corrections were made. Although, these examples are site-specific and with different plan forms, they provide a quantitative picture of what actually happens when buildings are constructed and then maintained. Therefore, the experience and the process may be utilised to develop an impact assessment tool for other contexts with modifications of the unit costs and embodied energies according to the local conditions. Such a tool will help the decision makers to understand the implications of different construction technologies and enable them to make informed choices for social infrastructure planning. This may particularly be useful for the Government policy makers, who have been facing the challenge of supplying the basic minimum services to citizens.

Decision making in India takes place at several levels of administration, starting from the Union Government in New Delhi to the village level through the State Governments, District and Block administrations. This chapter attempts to develop a simple tool for impact study that may be used by the decision makers. However, the results of such studies may be presented in user-friendly formats for the decision makers and stakeholders at different levels of infrastructure planning to make the process transparent and understandable. It is expected that such tools based on Andhra Pradesh Primary Education Project experience will lay the foundation for similar regional level data collection in other contexts to make a national level database centre for sustainable decision making on infrastructure planning in different parts of India.

At this point, it may be important to discuss the domain of the impact-study tool. Since the main focus of this dissertation is on achieving sustainable social infrastructure in India, a detailed literature review has been carried out in chapter 2 to understand the international level policies and guidelines on sustainable development. In the light of the literature review, the impact assessment tool in this dissertation assumes that the social infrastructure development programmes should be community-centred and the Government should adopt assessment of every project for sustainability. Based on the discussions in chapter 2, the impact assessment tool will be developed based on the following.

1. Considering the magnitude of shortfall in basic minimum services (chapter 3) and the lack of adequate funding to supply them (Tenth Five Year Plan, 2002-2007), use of technologies to reduce the unit cost of construction will enable us to build more within the resources.

2. The use of local materials and labour-intensive technologies will support the Government of India's efforts in Tenth Plan towards poverty eradication by creating more employment and income multiplier effect than the conventional cement and steel-intensive systems.

3. While trying to achieve the above two points, care should be taken so that the materials and methods of construction do not recklessly deplete the natural resources. This may be achieved by adopting the following.
   - By using materials of low embodied non-renewable energy in construction,
   - Preference of embodied renewable energy over the non-renewable energy,
   - Encourage those technologies which are based on industrial and agriculture waste,
   - Use technologies with low CO_2 emission.

4. The life cycle impacts on socio-economic and environmental impacts of the item "2" and "3", described above, should be considered.

In 1992, world leaders and scientists met at the United Nations Summit in Rio de Janeiro. They discussed the world's economy and how this was affecting the environment and, therefore, having impact on human life. Issues such as climate change, the destruction of forests and the consequential loss of plant and animal species were discussed. However, it was agreed that people could not be expected to preserve the environment when they were unable to earn a living, or achieve a decent standard of living for themselves and their families. They decided that it was important that decisions and actions taken to protect and preserve the environment should be balanced with the need to increase social equity and develop economic security (Kennett, 1998).

7.2. THE DOMAIN OF SUSTAINABLE INFRASTRUCTURE DEVELOPMENT

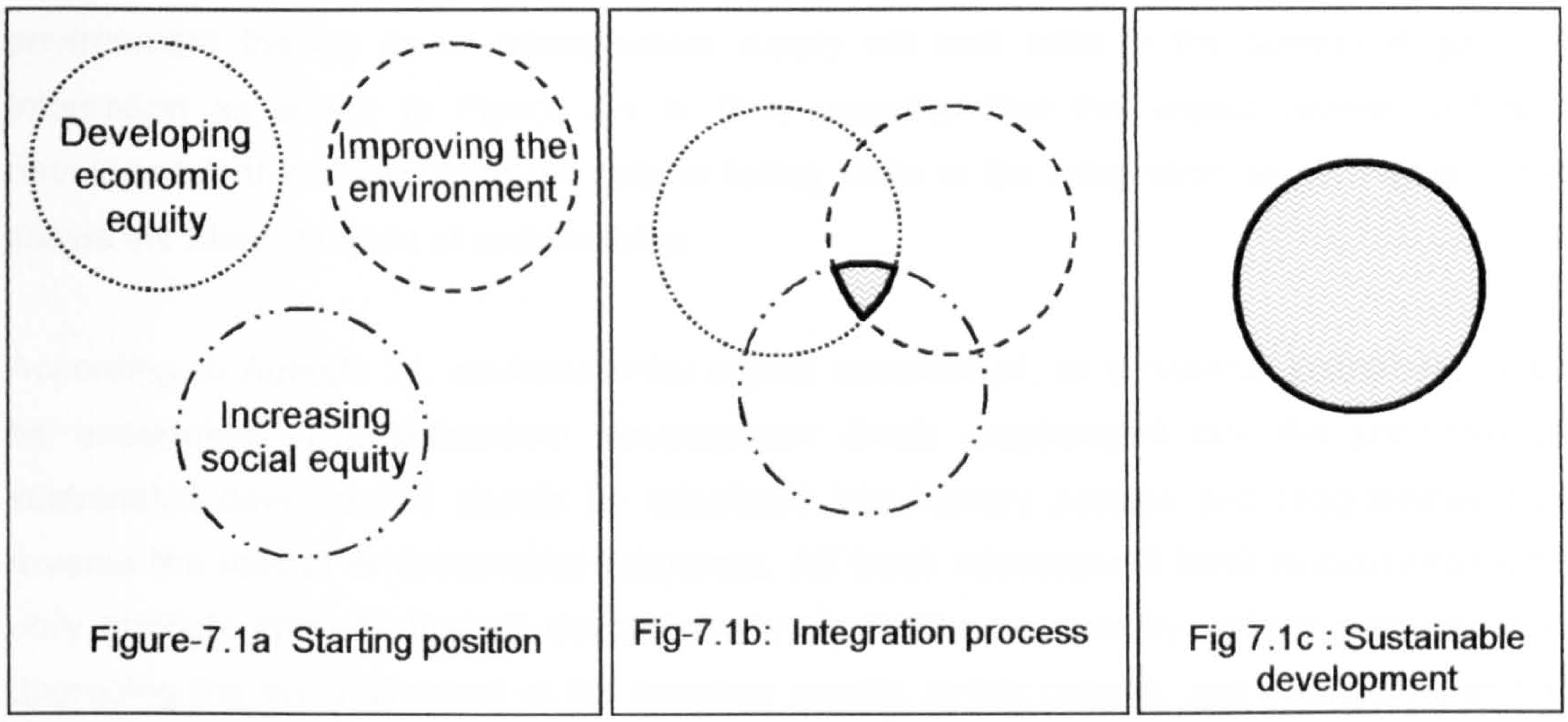
It is widely acknowledged that the growing focus on environmental issues is associated with a cultural shift in society at large (Emmitt, 1998). Emmitt refers to Newton and Harte (1997) to state that the majority of literature concerned with 'green issues' (chapter 2) has been criticised for having a strong environmental evangelism. Concerning buildings, the literature tends to concentrate on ways of reducing the emission of CO_2 to limit global warming. Emmitt (1998) further mentions that, in contrast, a few researchers have looked at the more 'soft issues', the issues related to the way individuals communicate, interact and shape a building project during its life.

While reviewing the existing methods of impact assessment in chapter 2, it appeared that the focus of the research in this field, especially in the developed countries, has been primarily on environmental protection. According to Cooper (1999), the Building Research Establishment Environmental Assessment Method (BREEAM), Green Building Challenge '98 and the other existing methods for assessing buildings are largely restricted to an environmental protection and resource efficiency agenda and hence, have a limited utility for assessing 'socioeconomic' as opposed to 'environmental' sustainability. It may be noted that similar opinion on the short coming of Green Building methods have been put forward by Todd and Geissler's (1999), They suggested that a regionally-adaptable impact assessment system taking into account of the social and economic issues, begins to address the sustainability of buildings.

Therefore, there is need for being sensitive to the social context while developing any method of impact assessment. Since poverty is high in India (Tenth Five Year Plan, 2002-07) the Government and a majority of the people will prefer livelihood generating construction technologies based on local materials and labour-intensity. In comparison, the impacts of construction on the environment may be of importance to the Government. The experience of introducing cost effective and environment-friendly systems in Andhra Pradesh and Orissa revealed that there was a conflict of interest between the people and the Government as far as the environment is concerned, which may be attributed to the absence of incentives for accepting such technologies and lack of awareness.

It may be reiterated that the environment provides goods and services that sustain human development so we must ensure that development sustains the environment. Therefore, to have sustainable development, one needs to bring together improving the environment with increasing social equity and developing economic security. Kennett (1998) has shown how these three issues are interlinked through three phases to a totally sustainable situation (Figure 7-1). Kennett (1998) states that according to the Rio summit, it is important that decisions and actions taken to protect and preserve the environment should be balanced with the need to increase social equity and develop economic security. Based on that, he recommends that the concept of sustainable development brings together improving the environment with increasing social equity and developing economic security. There is a need to minimise the environmental costs of a project and maximise the social and economic benefits.

Figure 7-1 The different states of sustainable development leading to an ideal situation



Source : Kennett, 1998, p.8.

Figure 7-1c represents the ideal stage when the society is transformed through a cultural shift (as Emmitt (1998) suggests) towards sustainable development. At present, the Indian situation appears to be like Figure 7-1a, where the three bubbles are coming close to each other. This may be said in view of India's growing awareness of the social and economic aspects of development programmes evident from the various community-centred social infrastructure development programmes such as the District Primary Education Programme. There is also an increased awareness about environmental protection in the Government sectors (Verma, 2000). It may be noted that, since the1990s, there has been a new architectural movement in India that is based on community-centred cost effective construction technologies (Das, 2000). Development programmes, such as the Orissa Health sector reforms and the District Primary Education Programme, are based on loans and financial assistance from international institutions and have been promoting community-centred infrastructure delivery (DPEP, 1995). A national evaluation of the education infrastructure construction under District Primary Education Programme was initiated in 2002. With the help of a team of sociologists, educationists, pedagogues, architects and engineers, the education infrastructure in eighteen states were evaluated and the synthesis report has revealed that community-based construction has the potential for sustainable development in India.

"The national evaluation revealed that the community based construction using innovative designs and cost effective construction technologies had helped in creating a better learning environment. It has a great potential for sustainable education infrastructure development. Therefore, it is strongly recommended that the national bodies and states continue to promote this newly evolved paradigm of social infrastructure development in programmes like Sarva Shiksha Abhiyan (SSA) etc." (Das et al, 2004:52).

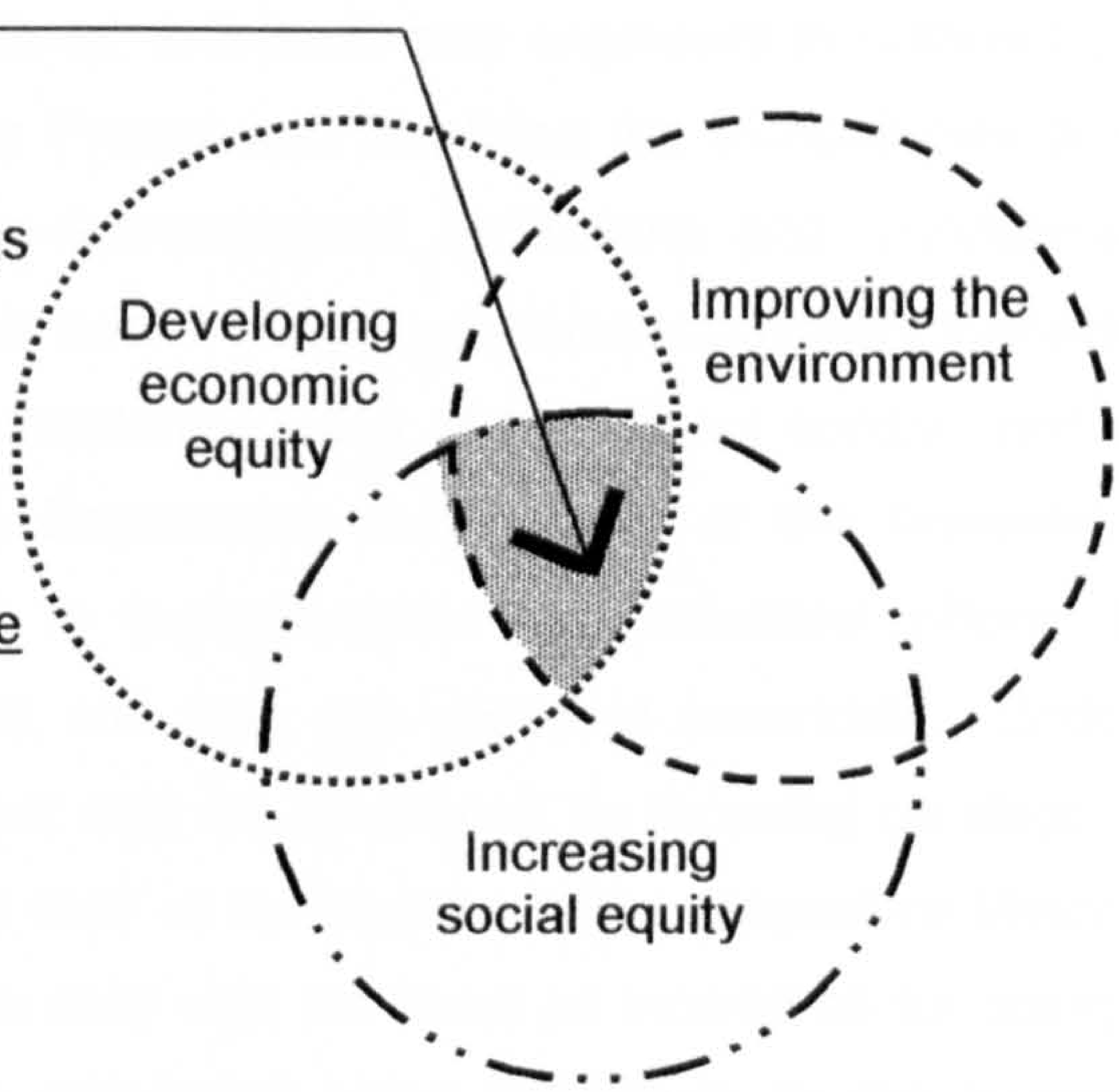
Therefore, with sustained effort of community-based, socio-economically beneficial and environment friendly social infrastructure supply will lead India to the second stage, i.e., integration as shown in Figure 7-1 b. It is expected that the impact assessment tool developed in this dissertation will help in taking India to the integration stage. Figure 7-1 c shows the ideal situation of sustainability.

According to Agenda 21, environmental impact assessment, as a national instrument, shall be undertaken. The Millennium Development Goals emphasized that the principles of sustainable development should be integrated into country policies and programmes and reverse the loss of environmental resources. All these international level recommendations very strongly promote that all developments should be pro-poor by reducing poverty and upgrading the living standard of the common people. In this context, and especially with the implementation experience of the Andhra Pradesh Primary Education Project's Repair and Upgrading programme, the following may be the diagrammatic representation of the domain of an impact assessment tool, which is in line with the international goals and also based on the suggestion put forward by Kennett (1998).

Figure 7-2 The domain of sustainable social infrastructure in India

SUSTAINABLE SOCIAL INFRASTRUCTURE DEVELOPMENT

1. Awareness campaign on green buildings
2. Incentives for accepting green building technologies
3. Community participation
4. Use of local materials and cost effective construction technologies
5. Use of green building materials
6. Use of labour intensive technologies
7. Use of green building technologies



Source: Author, based on Kennett, 1998, p.8.

The Figure 7-2 shows a seven-step process towards sustainable social infrastructure development in India. It has primarily been based on the field experience of community-centred construction process in Andhra Pradesh and Orissa. Out of these, steps 1 and 2 are mostly in the domain of the Government, e.g., policy, building regulations, etc. It is to be noted that the Government of India encourages any installation of pollution control devices and schemes and have introduced fiscal incentives. According to Gupta (1998) Customs duty is levied at reduced rates on equipment and spares for pollution control. Excise duty, at reduced rates, is charged on manufactured goods that are used for pollution control.

Manufacturing of building materials based on industrial wastes that contribute to environmental pollution receive excise duty concessions. To create awareness among the consumers, a scheme for environment-friendly labelling of products has been initiated. The scheme is for the twin purpose of encouraging both the manufacture and the use of such products. National Awards have been instituted for recognition of outstanding activities for the prevention and control of pollution.

However, these do not appear to have any impact on rural people, which is evident from the field experience of Andhra Pradesh and Orissa. The experience of Andhra Pradesh Primary Education Project reveals that the communities, to a great extent, understand and appreciate the advantages of cost effective construction technologies in rural buildings because they have experienced that the cost savings had enabled them to create more floor space or add facilities such as boundary walls. However, the villagers find the issue of environment-friendly technologies difficult to understand since there is no awareness campaign and incentives associated with it.

Step 3 has already been emphasised by the Government policies and various programmes, such as "Sarva Siksha Aviyan" (education for all). These programmes are being implemented by involving the communities. The steps 4 to 7 are being promoted by many institutions, Non-Governmental Organisations, architects and engineers in different parts of India. Andhra Pradesh Primary Education Project had identified the technologies promoted by them. Some of these specialist Non-Governmental institutions and individuals were appointed for constructing primary schools based on the environment-friendly materials and technologies. The planning, design and implementation of the school construction project were done through the Panchayati Raj Engineering Department of the Government of Andhra Pradesh. This was an attempt to institutionalise the individual efforts. During construction of these buildings in 1995-96, site data was collected accurately. Under such circumstances, the impact assessment tool may be developed by focusing on steps 4 to 7. Once the model is used by the technical staff of the bureau or the respective Ministry, the results will enable the decision makers to deal with the issue of incentives for using green building systems. They would like to be convinced about the return on the incentives in quantitative terms and also the required time frame. It is suggested that the decision-making process and the results of impact assessment will be presented in suitable formats for the different stakeholders of social infrastructure development in rural India. This will make the process of decision making transparent, which is not the case at present. Thus the use of the impact assessment tool will indirectly help in achieving the steps 1 to 3.

The Andhra Pradesh database will be used to examine the various options of relevant construction technologies, which generate low life-cycle cost, create livelihood and are the least damaging to the environment. If one wants to use the tool in a different context, the lead chart (in Figure 1.9, chapter 1), showing the sources of materials and their distances from the site, taxes, loading and unloading charges, should be changed according to the site-specific data and also in accordance with the local Government engineering department's standards. With this approach, technologies adopted for social infrastructure construction will tend to be sustainable in the rural India context. To do that exercise, one needs a method and the method needs parameters.

7.3. IDENTIFICATION OF PARAMETERS

It may be noted that sustainable social infrastructure development involves social, economic and environmental parameters (chapter 2). In this dissertation, the first two have been combined since they are monetised. Therefore, the number of categories of parameters has been reduced to socio-economic and environmental. The following paragraphs analyse and arrive at the parameters under these two categories.

7.3.1. Socio-economic Parameters

The example of Barikpur and Panasapada in chapter 4 (Figure- 4.4 and 4.5) show the impact of using local materials and labour intensive technologies on the construction workers' pattern of living. It shows that more labour-intensive technologies would enable them to have a better standard of living than what they earn from the conventional steel and cement-intensive technologies. However, this is valid in the context of the Tenth Five Year Plans' (2002-07) attempt to create high level of employment in the coming ten years. Under the socio-economic category, unit cost of construction, labour intensity and the degree of income multiplier effect are the three parameters. However, one may argue that the advantages of using local materials are not important since use of cement and steel is nevertheless benefiting someone somewhere in the country. There may also be other questions, e.g., what is the evidence that the use of local materials leads to a larger income multiplier effect?

Let us analyse the issues, such as local materials and income multiplier effects. It may be noted that any effort towards sustainable rural infrastructure development in India should preferably be around the problem of huge shortage of social infrastructure, discussed in chapter 3. The Tenth Five Year Plan of the Government of India not only indicates the magnitude of this problem, it emphasises that eradication of poverty has been one of the major objectives of the development planning process.

"At the beginning of the new millennium, 260 million people in the country did not have incomes to access a consumption basket which defines the poverty line. Of these, 75 per

cent were in the rural areas. India is home to 22 per cent of the world's poor. Such a high incidence of poverty is a matter of concern in view of the fact that poverty eradication has been one of the major objectives of the development planning process. Indeed, poverty is a global issue. Its eradication is considered integral to humanity's quest for sustainable development. Reduction of poverty in India, is, therefore, vital for the attainment of international goals." (Tenth Five Year Plan - 2002-2007,chapter 3.2:2)

However, the efforts to address the issue have been in existence prior to the Tenth Five Tear Plan. For example the National Housing and Habitat Policy (1998) recommended that technology would be particularly harnessed to meet the housing needs of the poor and also specific requirements of rural housing. It has emphasised the use of local materials in construction by recommending that *"Research efforts must also be directed to use locally available raw materials as far as possible." (NHHP, 1998:13)*

UNCHS/ILO (1995) refers to ILO (1984) and states that the marketing and transport of materials produced by small-scale units should also generate more employment than those of the output of large-scale products. The same publication (UNCHS/ILO, 1995:98) mentions that *"Small-scale, relatively labour-intensive building-materials manufacturing technologies are generally associated with larger multiplier effects than large-scale, capital-intensive technologies*

UNCHS/ILO (1995) refers to the earlier UNCHS (Habitat) publications (UNCHS, 1989, for example) to state that increasing employment and income-generating opportunities should not simply be an "optional extra" but a major consideration in the development of the most suitable approach to shelter delivery. It examines, therefore, the potential for reducing costs and improving efficiency in the provision, maintenance and management of urban services while at the same time increasing employment opportunities.

The above analysis indicates that both Government of India and the international institutions encourage the use of local materials for pro-poor development since it creates more employment and larger multiplier effects. However, the construction industry alone can not eradicate the poverty problem; it can partially help to improve the situation. Therefore, lowering the unit cost of construction, use of labour-intensive systems and adopting local materials-based technologies will help in achieving the objectives of the Tenth Five Year Plan. The identified parameters under socio-economic aspects are shown in Table 7.1.

Table 7.1 The identified parameters under the socio-economic category for the impact assessment tool.

Sl no	Symbol	Parameter	Objective
1	k=1	P1- Unit cost of construction.	To achieve lowest cost.
2	k=2,3,4	P2, P3,P4 Skilled, semi-skilled masons and unskilled workers' Labour-intensity.	To achieve labour-intensive techniques to create more employment for the skilled, semi-skilled and unskilled construction workers than the steel and cement-based systems.
3	k=5	P5- Money retained within the district boundary.	Use of local materials to support the local people involved in production and (or) trading in the construction sector.

P1 – Unit Cost Of Construction

In the Indian context, low unit cost of construction, especially in terms of life cycle costs, is necessary considering the huge need for the basic minimum services described in chapter 3. At present, the development projects implemented by the district collectors adopt only reinforced cement concrete based systems, which are costly because of high cost of cement and steel. Under the District Primary Education Programme, each educationally disadvantaged district was given 100 million rupees (£1.25 million) for physical infrastructure construction. This money is mostly soft loan from the World Bank. In the social infrastructure sector of India, there is a large gap between the supply and demand which has been discussed in chapter 3. Under such circumstances, low life cycle cost of a combination of foundation, wall and roof will be sustainable. Therefore, this is an important parameter in social infrastructure planning.

P2, P3, P4 - Labour Intensity:

Labour-intensive technologies are good for employment generation. The labour component has been sub-divided into skilled, semi-skilled and unskilled since that is the traditional way of classifying them in India. A construction worker attains the status of a skilled mason through an apprenticeship under a skilled mason over a period of about ten years. The semi-skilled masons are the apprentices after a training period of more than two years. The unskilled workers are those who do not aspire to be masons, or who have just entered the construction industry.

The Andhra Pradesh experience has shown that some technologies are skilled labour-intensive and the others are unskilled labour-intensive. It is important to know the impact of technologies on livelihood of different categories of construction workers. It may be noted that the recent work on economic growth has brought out sharply the role of labour, education and experience and the so called human capital. The central issue in economic development is to expand the social opportunities open to the people (Dreze and Sen, 1998).

Therefore, introducing labour-intensive construction technologies will not only support the livelihood of the construction workers, the increased employment opportunities will enhance their skills, thereby transforming them to more productive human resources. Therefore, it is important to examine the labour intensity of construction technologies in a particular context of social infrastructure programmes.

P5- MONEY RETAINED WITHIN THE DISTRICT BOUNDARY

In social infrastructure construction, the builders and building material suppliers earn money, which they spend on food and other products produced in the country. So far as this produces chains of consumption within the country, the consumption multiplier effect will increase. The site experiences of Andhra Pradesh and Orissa revealed that the construction workers and the local suppliers spent most of their earnings on locally produced food such as rice, wheat, fish, etc. In discussions on multipliers, the direct increments to income and employment are referred to as first round effects. The spending generated by these fall through subsequent rounds depending on a propensity to spend money on imports, to pay tax and to save.

UNCHS/ILO (1995) refers to Grimes (1976) who, on evidence from Colombian Government research, estimated that the income multiplier for low-cost housing construction is about two. Similar results can be gained in India, Mexico and Pakistan. This is supported by Moavenzadeh (1987) who predicts developing country multipliers of less than the United States of America where it is estimated at 2.35. Since Andhra Pradesh Primary Education Project and Orissa Health Project were primarily based on local materials, one would expect an enhanced income multiplier effect at local level. Apart from this effect, the use of local materials will encourage the small scale units to increase their production, which will create employment at local level.

7.3.2. Environmental Parameters

The literature review in chapter 2 revealed that the environmental impact assessment in this dissertation should be based on embodied energy and CO_2 emission of different construction technologies. Out of the different environmental assessment methods discussed in the chapter 2, "Green Building Challenge" appears to have a considerable influence in the field of environmental sustainability. Therefore, we shall continue with the discussion on green building in the context of environmental parameters in the impact assessment tool.

Woolley et al (1999: 5) refers to Robert and Brenda Vale(1991) and state that the definition of green building is; *"that a green approach to the built environment involves a holistic approach to the design of buildings; that all the resources that go into a building, be they materials, fuels or the contribution of the users need to be considered if a sustainable architecture is to be produced."* Johnson (1993) talks about how the environmental impact of individual properties can be mitigated. According to Ryn and Cowan (1995), we must infuse the design of products, buildings and landscape with a rich and detailed understanding of ecology. In the light of these definitions, Woolley (1999) suggested that green building should consider reducing energy in use, minimising external pollution and environmental damage, reducing embodied energy and resource depletion and minimising internal pollution and damage to health.

It may be recalled from chapter 2 that the Green Building Challenge was initiated in 1995. According to Todd et al (2001), it was not designed for application to specific commercial markets. Instead, it emphasised research and involved researchers and practitioners from many countries. According to Todd et al, some of the Green Building tools are structured around design strategies (which can be viewed as system inputs) and others are structured around environmental loadings or impacts (which can be viewed as system outputs). Most systems exhibit some combination of these approaches. The Green Building Challenge and most other systems based on environmental topics rate the building on its resource consumption, contribution to global warming and other environmental parameters.

It has been observed that most of the literature on green building act as general guidelines. Woolley criticises the literature on the Green building movement by stating that; *"Many people who want to behave in an environmentally friendly way find such literature frustrating because it is often preaching the converted. What they want to know is not so much the general picture, though this is of course important, but more practical information on how to actually do things"* (Woolley et al,1999:4).

If we take the last part of Woolley's suggestion on how actually to do things as a challenge, it may be worthwhile to conduct in-depth examination into the local context of impact on the environment. The example of Barikpur and Panasapada in chapter 4 has already demonstrated the impact of different construction technologies on the environment at grass-root level in the context of rural Orissa, India. These two examples showed how rat-trap bonded masonry wall had saved bricks compared to the conventional solid brick wall at Barikpur. This had also reduced the emission of CO_2. Panasapada had been more energy efficient, since it had used 12,000 fly-ash blocks for a covered area similar to that of Barikpur which meant that it had saved the consequences of 75,000 bricks. In addition, the use of fly-ash has cleaned up harmful waste from the thermal power plants.

The construction industry in India is the single largest consumer of many energy-intensive materials, of which, cement and steel account for a large share of the total energy. The production of building materials account for nearly 25% of the total energy budget of India (Gupta, 1998) and thus energy efficiency in production process is very important. Furnaces and kilns used in the production of steel, cement, bricks and ceramics, etc., are operated at very high temperature. In India coal is used as fuel and hence, the emission of CO_2 is very alarming (Gupta, 1998). India may be the most populated country in the world by 2025 and its Green House Gas emissions may rise substantially. Despite the fact that in 1986 it emitted only 0.2 tonnes per capita of fossil CO_2 (compared to 5.4 tonnes per capita in the USA), it is the sixth largest CO_2 emitter in the world (Parikh and Gokarn, no date). There is worldwide interest among the scientists and environment policy makers regarding the increasing global warming, particularly owing to the increasing emission of CO_2. There is, therefore, a strong need to improve energy efficiency of manufacturing processes which would lead to reduction in CO_2 emissions

However, burnt clay brick, lime, ceramic and glass industries have been particularly indifferent to energy saving measures except for a few large manufacturing units. An interesting outcome of the ban imposed on the use of primary wood in Government construction is the increased use of Aluminium, steel and PVC components although these are regrettably high energy-consuming materials. Brick manufacturing is mostly un-organised, fragmented and widely distributed throughout the country. The production of brick has gone up by ten times since independence. This industry is responsible for removing the topsoil and quarried material to the extent of severely damaging the local and regional environment (Gupta, 1998). At this point it is important to examine all the issues discussed above.

EMBODIED ENERGY

A detail investigation carried out on embodied energy of building materials revealed that, of all the sources available in India, the data provided by the Development Alternatives was the most acceptable (Energy Directory of Building Materials, 1995). The Building Materials and Technology Promotion Council had appointed Development Alternatives, New Delhi to prepare an Energy Directory of Building Materials. This document describes the process of embodied energy analysis, which is based on;

- energy for quarrying, including transportation to production site,
- energy for raw material processing (including energy for basic raw materials),
- energy for production of materials including thermal and electrical but ignoring manual labour.

It may be noted that the production capacity and technology of production process regulate the embodied energy content of the products. The Development Alternatives' calculations have been based on common practices of production technology. It has also been based on the best practice which is usually characterized by adopting energy efficient measures without significantly changing the technology or type of fuel used.

The site and infrastructure of the production units have not been considered in the energy calculations. Considering these different sources, Development Alternatives' data is acceptable, since it shows the process of embodied energy calculations. It may be reasonable to accept this as baseline data on embodied energy, which is the total energy per unit of the finished materials at factory. Based on this data, the chapters 8 and 9 show the process of calculating embodied energy of the construction materials at different levels in the context of Ranga Reddy district. To compare with Development Alternatives' data, embodied energy of a few items such as bricks were calculated from first principles based on primary data collected from the production yards. Such data in the context of Ranga Reddy district were found to be close to Development Alternatives' data.

CO_2 EMISSION

The issue of CO_2 has been discussed in chapter 2. UNCHS(Habitat) (1991) reports that the pollution problem caused by building materials industries constitute a substantial part, account for nearly 20% of world fuel consumption. However, it has attracted the attention of the environmentalists only recently. Fay et al (2000) refers to Pears (1997) and states that the significance of greenhouse gases attributable to building operation is well understood. Parikh and Gokarn (no date) reports that India and China are considered to be major players in global climate change because of their likely increase of CO_2 emissions owing to increases in income and level of population. Moreover, both depend on coal.

In India, coal and firewood are used as fuel for brick production. However, there are places where rice husk and other types of non-wood are used in brick and clay tile manufacturing processes. It has been mentioned earlier that rice husk is used in Ranga Reddy district for brick manufacturing. Levine (1994) refers to Bowen (1979) to state that the Biomass material contains about 40% carbon by weight, with the remainder hydrogen (6.7%) and oxygen (53.3%). According to the report of Biomass One stop Cleaning House (2003:12) carbon content of rice husk is 34.58%. The above discussion tends to suggest that the impact of construction on CO_2 emission needs to be considered at infrastructure planning stage.

NON-RENEWABLE ENERGY AND CO_2 EMISSION FOR TRANSPORTATION OF MATERIALS FROM THE OUTLET TO THE SITE.

Appendix I shows the embodied energy and CO_2 emission of different materials for quarrying, transportation of raw materials from the source to the site and production of the materials at the outlets. Therefore, the additional energy for transporting these materials from the outlets to the site via distributors should also be calculated. Cement, steel, etc., are produced in large plants and are transported to the cities and town to the distributors. They are then transported to the respective sites from the distributors. At the district level, the engineers' lead-chart (in Figure 1.9, chapter 1) shows the distances from cement and steel distributors to the sites. However, information on distances from factories to the distributors may not be difficult to obtain and each state Government engineering department can generate such information to study the impacts accurately.

There may be different databases for transport energy in different parts of the country depending upon the road condition, topography, climate, etc. For example, while evaluating energy efficiency of apartment housing in Sweden, Thormark (2002) simplified the calculation of energy for transportation of materials to the building site in the following way. He assumed that 75% of all materials, except crushed rock, were, on average, transported 350 kilometres in a large truck, filled to 70% and 90 kilometres in a truck of medium size, filled to 50%. Crushed rock was assumed to be transported 75 kilometres in a truck of medium size. With these assumptions, the total energy needed for transportation was calculated as 44 kilo Watt hours per square metre of floor area. According to Thormark, this result agreed well with more exact calculation in Adalbert (1997). In the present context, the lead chart of Jaggamguda, Ranga Reddy district has been adopted and the fuel consumption of a 12 tons capacity diesel-operated truck has been taken from the Tata Energy Data Directory Yearbook (TEDDY, 1993).

THE ISSUE OF LOSS OF SOIL

As mentioned before, there is a need for 600 billion bricks in India for the period 2001-2006 (BMTPC,STEM, 2000). India produces about 100 billion bricks every year (Maithel and Uma, 2000). To the common people in the rural areas, brick-built shelters are considered to be permanent. While its popularity has increased the production, there has been a general apathy towards quality control in brick production. There is very little sense of competition or incentive for producing better brick since even low quality bricks has a market. The impact of 100 billion bricks per year needs a review. While the issue of CO_2 related to brick production has already been discussed, we need to investigate the other aspects of impact on environment in brick production. According to some researchers (Dev, 1994) the loss of top soil for brick production is significant and may have negative impact on agricultural production in the long run. However, such calculations have assumed that brick manufacturing will consume soil up to 1200 millimetres depth which may vary from region to region. In many states brick is manufactured by using clay collected from the rivers and, hence, the issue of soil loss owing to brick making does not apply. Apart from that there is a lack of adequate information relating to the issue of loss of soil and hence, this has been excluded from the impact assessment tool. However, it is suggested that separate in-depth research should be carried out to understand this aspect of the construction industry.

RECYCLING OF MATERIALS AT THE END OF THE BUILDING'S LIFE

Apart from the energy consumption, certain key issues will also be dealt with. Construction activities mean depleting materials, if they cannot be recycled. According to Jankovic (1999), recycling in the construction industry is becoming important. In many Western European countries, facilities and institutions have already been established to recycle waste generated from construction and building industry. Thormark (2002) states that the recycling potential of the most energy efficient apartment housing in Sweden (45 kilo Watt hour per square metre), in a life span of 50 years, accounted for 45% of the total embodied energy. The recycling potential was between 35% and 40% of the embodied energy. It may be noted that 70 million tons of construction waste is produced each year in the UK and only 20% (at present) is recycled (Raynsford, 1999).

At present, in India, recycling of blast furnace slag in cement manufacturing and mixing fly ash to cement is already in practice (Gupta, 1998). The structural sections such as rolled steel joists and reinforcing bars, if not corroded, are recycled. Timber is also recycled. However, most of the construction materials after demolition of buildings are used for land filling and not recycled in new construction in form of aggregate in concrete, etc. These may, therefore, be treated as depleted once used in a building construction. As with the issue of soil loss owing to brick making, this aspect of environmental impact needs separate research and hence, it has been excluded from the impact assessment tool.

The environmental aspects of the impact assessment tool in this dissertation have considered only the embodied energy and CO_2 emissions of different construction materials and technologies. However, it did not attempt to analyse and calculate such unit energies and emissions from the basics since these are outside the scope of this dissertation. The assumptions and methods of calculating embodied energy and CO_2 emission have been described in chapter 8. Issues such as loss of soil owing to brick making has been discussed but not included in the assessment tool. This dissertation will, therefore, deal with the following environmental parameters only.

Table 7.2 The environmental parameters considered for impact assessment tool

Sl no	Symbol	Parameter	Objective
1	k=6	P6- Non-renewable embodied energy	To achieve the lowest quantity
2	k=7	P7- Renewable embodied energy	To achieve the lowest quantity
3	k=8	P8- Use of embodied energy from agricultural waste.	To achieve high consumption
4	k=9	P9- Emission of CO_2 owing to the use of different materials and construction technologies.	To achieve the lowest quantity

7.4. WEIGHTING

According to Todd (2001), weighting systems are fraught with difficulty since they cannot be accomplished with complete, or in some cases, any, scientific objectivity. He refers to Dickie and Howard (2000) and states that, in the absence of any scientifically derived weights, some organisations use 'consensus-based' weighting. In this approach a group of specialists or users rank various elements, such as environmental issues, in terms of their relative importance or assign points to these elements. The Green Building Challenge framework provides a default weighting system and allows users to change the weights based on regional or other priorities. Weighting itself is an area of exclusive research and, in this dissertation, the impacts of varying the weightings have been demonstrated instead of recommending them.

7.5. METHOD OF EVALUATION

After identifying and discussing the nine socio-economic and environmental parameters, now the discussion will be focused on a tool for assessing impact of the different construction technologies. It has been assumed that, in the planning stage of a social infrastructure programme for an area, a resource mapping exercise will be carried out to identify the locally available materials, skills, socio-economic conditions, availability of electricity and water supply, road conditions, vernacular architecture, etc. Based on the collected information, a list of feasible technological options for that particular location will be identified with the help of Appendix III and Appendix IV. The impact assessment tool will then calculate and show the scores of all the options in that locality from socio-economic and environmental factors. Let us now look at the impact assessment tool in the following paragraphs.

A detail discussion on the available assessment tools have been carried out in the chapter 2, in which, the most influential tool appeared to be the Green Building methods. However, there are criticisms on the Green Building methods. Kohler and Lützkendorf (2002) state that the designers, owners and developers of buildings have been demanding simplified ratings of building performance to identify 'green' buildings on the market. They opine that while a number of assessment tools are available, they are not well suited for the use of comprehensive planning teams. Apart from these shortcomings, there is a fundamental difference between the Green Building methods and the impact assessment tool in this dissertation. The main objective of this dissertation has been to develop an impact assessment tool based on the data and experience of the Andhra Pradesh Primary School Project. Therefore, it is a completely bottom-up approach and hence, attempting to adopt the existing assessment methods in the context of Andhra Pradesh-based data does not appear to be feasible. Considering these, a simple impact assessment tool has been developed in the following paragraphs.

There are nine parameters that will evaluate the different combinations of walling and roofing systems. The units of the first five parameters are in rupees, the sixth to eighth are in Mega Joules and the ninth in tons. Ideally all the environmental parameters should have been monetised to make them compatible with the data on socio-economy, which are in rupee value. Let us look at how others have dealt with this problem. Some researchers have treated the socio-economic and environmental parameters separately to study the impacts, e.g., Rolfsman (2002), studied the way in which CO_2 emission levels were affected by different measures to reduce energy consumption in a building. This was done with reference to a case study of a residential building in Navestad, a suburb of the Swedish city, Norrkoping. Three different energy measures were adopted for retrofitting, viz., extra insulation, new type of window and introduction of a heat pump. For the ranking by cost, he had used the so called Optimal Energy Retrofit Advisory (OPERA) model, for which he referred to Gustafsson and Karlsson(1989). In this model several retrofit options were optimised using the present value method while calculating the life cycle costing, which included building maintenance and operating costs. He ranked the measures by cost and CO_2 reduction by consumption.

Roulet et al (2002), while developing a multicriteria rating methodology for buildings, also dealt with criteria of different units. They had solved the problem of combining different units as follows.

"As the variables come in different units, it is preferable to homogenise them by dividing each one by the corresponding standard deviation value" Roulet et al (2002:581).

The problem of homogenising different units in this dissertation has been solved by adopting index method of calculation. Let us now understand how it works. The number of possible technologies (n) is assumed as the number of students in a class. The group of socio-economic parameters (P1-P5) and the environmental parameters (P6-P9) will be treated as major subject-groups with different group weightings - GW_1 and GW_2. The parameters (P1 to P9) will be treated as subjects under the respective groups with different subject weightings – WP_1 to WP_9. The subjects will be termed as parameters in this section.

All the technologies will be evaluated under each parameter, viz., P1 to P9 on an Index scale, e.g., the technologies having minimum unit costs will be assumed to score 100 and the scoring of the remaining 'n-1' number of technologies will be calculated with respect to unit cost scoring 100. The following Table 7.3 shows the different conditions for 100% score of each parameter P_k, k=1 to 9. Thus the index method of scoring has eliminated the problem of combining the different units of the parameters.

Table 7.3 The conditions of index-100 of all nine socio-economic and environmental parameters.

Sl no	Groups	Parameter	Scoring
1	**Category-1** **Socio-economic**	**P1-** Unit cost of construction	The technology with the lowest unit cost has an index of 100
2,3,4		**P2, P3, P4 -** Money to the skilled, semi-skilled masons and unskilled workers.	The technology with the highest skilled mason-intensity has an index of 100 The technology with the highest semi-skilled mason-intensity has an index of 100 The technology with the highest un-skilled worker-intensity has an index of 100
5		**P5-** Money retained within the district boundary	The technology that retains the highest amount of money within the district has an index of 100
6	**Category-2** **Environmental**	**P6-** Non-renewable embodied energy	The technology with the lowest embodied non-renewable energy has an index of 100
7		**P7-** Renewable embodied energy **	The technology with the lowest embodied renewable energy has an index of 100
8		**P8-** Embodied energy by burning agricultural waste	The technology with the highest embodied energy has an index of 100
9		**P9-** Emission of CO_2	The technology with the lowest emission has an index of 100

Source: Author

** It may be noted that Raynsford's (1999) suggestion of encouraging renewable energy over non-renewable energy could be done by assigning lower weight to the renewable than the non-renewable energy parameter.

SCT_{11}, SCT_{12}, ... SCT_{1N}, are scores of the technologies for the parameter, unit cost of construction. The general expressions for the subject scores will be SCT_{kj}, where k=1 to 9 are the parameters and j= 1 to n are the technologies.

Table 7.4 Matrix showing subject index SCT_{kj}, subject and group weightings.

Group Weightings	Subject Weightings WP_k, k=1,9	Technology j=1	Technology j=2	Technology j=i	Technology j=n
GW1– socio-economic parameters	WP 1	$SCT_{1,1}$	$SCT_{1,2}$	$SCT_{1,i}$	$SCT_{1,n}$
	WP 2	$SCT_{2,1}$	$SCT_{2,2}$	$SCT_{2,i}$	$SCT_{2,n}$
	WP 3	$SCT_{3,1}$	$SCT_{3,2}$	$SCT_{3,i}$	$SCT_{3,n}$
	WP 4	$SCT_{4,1}$	$SCT_{4,2}$	$SCT_{4,i}$	$SCT_{4,n}$
	WP 5	$SCT_{5,1}$	$SCT_{5,2}$	$SCT_{5,i}$	$SCT_{5,n}$
GW2– environmental parameters	WP 6	$SCT_{6,1}$	$SCT_{6,2}$	$SCT_{6,i}$	$SCT_{6,n}$
	WP 7	$SCT_{7,1}$	$SCT_{7,2}$	$SCT_{7,i}$	$SCT_{7,n}$
	WP 8	$SCT_{8,1}$	$SCT_{8,2}$	$SCT_{8,i}$	$SCT_{8,n}$
	WP 9	$SCT_{9,1}$	$SCT_{9,2}$	$SCT_{9,i}$	$SCT_{9,n}$

Table 7.4 shows the indexes of all the technologies from the third column onwards (technology j=1 to n). The indexes $SCT_{1,1}$ to $SCT_{9,n}$ are without considering their respective weightings. It has been mentioned before that each parameter has a weighting and hence, the individual subject scores should be multiplied by the respective weightings and then summed up in the group, e.g.,

$$SEWI_1 = SCT_{11} \times WP_1 + SCT_{21} \times WP_2 + SCT_{31} \times WP_3 + SCT_{41} \times WP_4 + SCT_{51} \times WP_5$$

SEWI represents the total weighted index of a particular technology (j=1) against the five socio-economic parameters after considering the subject weightings WP1 to WP5.

$$ENWI_1 = SCT_{61} \times WP_6 + SCT_{71} \times WP_7 + SCT_{81} \times WP_8 + SCT_{91} \times WP_9$$

ENWI represents the total weighted index of the same technology against the four environmental parameters after considering the weightings WP6 to WP9.

The final total weighted index of a technology, e.g. j=1, would be as follows

$$WIT_1 = GW_1 \times SEWI_1 + GW2 \times ENWI_1$$

Therefore, the general expression of the final weighted index of the j^{th} technology "j" (i=1,n) WITj will be as follows.

Group weighting – GW1

Subject weighting –WP_k, k = 1 to 5

Group weighting GW2

Subject weighting –WP_k, k=6 to 9

$$WIT_j = GW1 \times \sum_{For\ k=1}^{to\ 5}\left(SCT_{kj} \times WP_k\right) + GW2 \times \sum_{For\ k=6}^{to\ 9}\left(SCT_{kj} \times WP_k\right)$$

For j =1,n, where n is the number of technologies

From the final weighted index (WIT_j, j=1,n), the highest element will be assumed to have an index of 100 and the remaining indexes will be calculated accordingly. The following chapters show that the impact assessment tool adopts 11 roofing systems and 6 walling systems, i.e., 66 combinations of technologies. All these permutations are possible. Therefore, 1x66 matrix will be generated for calculating the final indexes. However, for convenience of reading the input and output of the calculations, data has been presented as a 11x 6 matrix. The input and output of the model has been presented as in the matrices with the walling technologies in rows and roofing technologies in columns.

While all the impacts are important both at local and global level, some are more important at one level than the other. For example, the use of labour-intensive materials and methods of construction, especially with local materials, have a direct and more tangible impact at local level. Such actions will increase income-generating activities and help in improving living conditions of the construction related people. Therefore, the use of such technologies in construction partially helps poverty reduction and hence, is a global issue as well, which has been discussed in chapter 2. While the impacts of the depletion of non-renewable and renewable energy, emission of CO_2, etc., may have local level impacts, it is in general more of a regional, national and international concern (especially CO_2 emission). In many discussions in India, it has been observed that the decision makers and the technocrats show their concern over these issues without referring to the actual quantum of the impacts, which this dissertation has shown in chapter 5 and chapter 6 on Andhra Pradesh Primary Education Project and the Repair and Upgrading programme of the same. The method of evaluation evolved in this chapter, will help a decision maker to assess the most sustainable construction technology in a particular context. They can study the impacts of the weightings by assigning a particular set of values, which could be based on the decision makers' own experience or it may be by consensus of a group. The next step will be to study the outputs of the model in terms of actual quantities, which require a database. The next chapter will discuss the data required to run the model, which is based on the experience of Andhra Pradesh Primary Education Project.

CHAPTER 8 DATABASE FOR IMPACT ASSESSMENT: LEVEL-1 AND LEVEL-2

8.1 BACKGROUND OF THE DATABASE

It may be recalled that the chapter 5 on Andhra Pradesh Primary Education Project was to show the process of education infrastructure construction and it was expected that the experience will help in evolving an impact assessment tool. The impact assessment tool developed in the last chapter will calculate the impacts by using the database of Andhra Pradesh Primary Education Project. In order to use the impact assessment tool in any context, only the database should be modified. Therefore, understanding of the process of developing the database is as important as the impact assessment tool. This and the following chapter describe the process of data collection in the context of Andhra Pradesh Primary Education Project, which will enable decision makers to create databases in other contexts.

The scope of this dissertation in chapter 1 states that the average cost of construction, labour cost and embodied energy of wall and roof combined constitute a significant part of a complete building. It may be noted that the walling and roofing technologies include finishing items such as plastering, painting, roof waterproofing, etc. It is also explained in chapter 1 that one type of foundation, door and windows made of local timber and a stone floor finish were adopted in Ranga Reddy district. As a contrast, there was a wide variation of walling and roofing technologies. Since this dissertation intended to calculate the scores of the different options of technologies on a comparative basis, only wall and roof have been considered for impact assessment. However, in situations where a number of options are available for foundation, door, window and floor finish, the impact of a finished building should be considered.

It has been demonstrated in chapter 5 that different plan forms, site conditions and designs play significant roles on the socio-economic and environmental impacts. Since the main focus of the dissertation is on studying the impact of construction technologies, the effects of these aspects have been eliminated by assuming the following.

- Plan-forms and carpet areas are constant, i.e., square room with internal dimensions of 5.5 metres x 5.5 metres;
- The land is flat.

In order to understand the impacts of different combinations of walling and roofing systems, a classroom of internal dimensions 5.5 metres x 5.5 metres (used in Ranga Reddy district) has been adopted in this dissertation. The purpose of demonstrating the quantitative impact through a classroom is intended to enable the users of the tool to understand the results and could relate to a practical situation, i.e., if one constructs a room using a particular combination of wall and roof, how much will it cost? How much employment will be generated and to what extent will it affect the environment? The socio-economic and environmental database of the construction of different walls and roofs depend upon the types of materials and the processes involved at different stages of manufacturing, processing and fabricating, which have been categorized under the following heads.

- Level-1: Primary Manufacture, e.g., aggregate, random and coursed rubble stone, bricks, clay tiles cement, steel, lime, etc.

- Level-2: Secondary Processing- based on primary level materials for manufacturing micro concrete tile, pre-cast reinforced cement concrete planks, joists, channels etc. Level-2 is an intermediate stage and is made of level-1 materials.

- Level-3: Tertiary Fabrication – walls, roofs, doors, windows etc., i.e., complete components of a building, which are produced from either only from level-1 materials or a combination of level-1 and 2.

The above three levels were adopted by Development Alternatives, New Delhi, (Energy Directory of Building Materials, 1995) while calculating the embodied energy of different materials in the process of completing a building as a complete product. Since this energy data has been used in the present section, broadly the same categorisation has been adopted for consistency. However, brick and clay tiles have been put under level-1 in order to make level-2 exclusively for the pre-cast elements introduced for the first time in Ranga Reddy district. Level-2 in this dissertation refers to the pre-cast elements produced in the building centres, a new hub of employment generation in an organised manner, rather than through the master masons or carpenter.

As mentioned above, the impact assessment will be based on different combinations of walling and roofing systems, which are level-3 products and require inputs from the Level-2 and Level-1. For example micro concrete tile roof with steel and timber under-structure, requires micro concrete tiles (a Level-2 product) along with steel and timber, (i.e., the level-1 products). Costs of materials, labour and transportation under Level-1 have been adopted from the Standard Schedule of rates of 1995-96 published by the Government of Andhra Pradesh (Appendix II, Table II.2). The embodied energy contents of the Level-1 materials have been primarily from the Energy Directory of Building Materials (1995), except the paints, bitumen, waterproofing compound, etc., which were not covered. These have been adopted from the embodied energy of materials in New Zealand (Alcorn, 1998). While this appears to be inconsistent, the embodied energy of steel and cement in Indian context were similar to that of New Zealand. The matter was discussed with the researchers of the Tata Energy Research Institute in Delhi and they also agreed that, in absence of such data in the Indian context, one can adopt the one provided by Alcorn. This issue has been discussed under limitations in chapter 1.

The Level-2 and Level-3 data are primarily based on the Government of Andhra Pradesh's approved analysis of rates of both conventional and cost effective items. It may be noted that the cost effective items, e.g., micro concrete tile, planks, joists, etc., did not exist in the Government schedule of materials and products prior to Andhra Pradesh Primary Education Project. One of the important targets of Andhra Pradesh Primary Education Project was to get these items approved by the Government and then include them in the schedule of rate analysis. Therefore, a rigorous process was adopted by recording the on-site daily progress of work consisting of material and manpower requirements. For example, while constructing a rat-trap bonded wall, the masons were trained first at site. Therefore, in the first few days there was a very slow progress that improved over the next few days and in a week's time they became comfortable with the technology. The same masons were employed in another six sites where rat-trap was adopted. The average of this entire process was accepted by the Panchayati Raj Engineering Department for the analysis of rates of the technology. The Government engineers were a part of the process and in the end of the construction, they scrutinised the data before officially accepting them on the 31st March 1996. This data on rate analysis for level-2 and level -3 items shows the quantity of labour, materials, equipment etc., required per unit , e.g., for the production of 150 micro concrete tiles one would require 90 kilogram cement, 0.11 cubic metre sand, 0.04 cubic metre 6 mm aggregate, etc. Such data will be used for calculating costs, embodied energy and emission of CO_2 per unit elevation area of the finished walls and plan area of roofs per square metre.

JAGGAMGUDA AS THE REFERENCE SITE

One of the important aspects in a database is the location of the site with respect to the different sources of materials. The 29 cost-effective school construction sites in Ranga Reddy district had separate lead charts showing socio-economic and environmental data of level-1 materials. In this section, we could have adopted any one of them as a database since the entire process of impact assessment is developed on Microsoft Excel worksheets, where any change in the master table will automatically recalculate the data of level 2 and 3. The database of the village Jaggamguda, Ranga Reddy East, has been adopted since it was the first project site, in which the contractor had accepted the cost effective items as a formal contract under the Government of Andhra Pradesh. All the socio-economic and environmental data of level-1 materials are the basic input to the system, which has been presented in the Table-II.2, Appendix-II. The following level 1 building materials were required for the construction of all the walling and roofing systems under consideration.

Table 8.1 Local and non-local materials used in Ranga Reddy district under Andhra Pradesh Primary Education Project (level 1 materials).

Sl. no.	Description of level-1 materials		Sl. no.	Description of materials	
1	20 mm hard granite metal	Local	12	Lime	
2	6 mm hard granite stone chips	Local	13	Cement	
3	40 mm hard granite metal	Local	14	Steel reinforcement	
4	Random rubble stone	Local	15	Steel structural	
5	Coursed rubble stone	Local	16	Binding wire	
6	40 mm thick Tandur stone		17	Soil for cement stabilised mud block	Local
7	Sand for mortar		18	Wooden shuttering	Local
8	Sand for filling	Local	19	Wooden scaffolding	Local
9	Stone dust	Local	20	Timber for structural use	Local
10	Wire-cut brick	Local	21	Rubber based waterproofing compound	
11	Clay tile	Local	22	Diesel/litre	

Source: Author

Table 8.2 All the level-2 materials used in Ranga Reddy district under Andhra Pradesh Primary Education Project

Sl. no.	Description of materials	
1	Cement stabilised mud block (5%)	Local Building Centre
2	Interlocking cement stabilized mud block (10%)	Do
3	Stone concrete blocks	Do
4	Micro concrete tiles	Do
5	Pre-cast reinforced cement concrete planks	Do
6	Pre-cast reinforced cement concrete joists	Do
7	Pre-cast reinforced cement concrete channels	Do
8	Pre-cast ferrocement channels	Do

Note: All produced in the building centre at Aliabad, 2 kilimetres from Jaggamguda. All these are made of level-1 materials shown in Table 8.1.

Table 8.3: All the Level-3 materials used in Ranga Reddy district (walls).

Sl no.	Description of Level-3 materials: walling	Remarks
1	230 mm thick solid brick wall using wire-cur bricks in i:6 cement sand mortar	Wire-cut bricks from Rajbolaram
2	230 mm thick rat-trap using wire-cur bricks in i:6 cement sand mortar.	Wire-cut bricks from Rajbolaram
3	230 mm thick Cement Stabilised (5%) Mud Block (CSMB) masonry wall in 1:4:8 cement fine sand and mud	Blocks from the local building centre
4	150 mm thick Interlocking Cement Stabilised (10%) Mud Blocks (ICSMB) masonry in 1:6 cement sand mortar	Blocks from the local building centre
5	190 mm thick Stone Concrete Block (SCB) masonry in 1:6 cement sand mortar.	Blocks from the local building centre
6	380 mm thick coursed rubble stone (CRS) masonry.	Stone blocks from Turkapally

Note: All level-3 walling elements are either made of level-1 materials only or a combination of level-1 and level-2 materials.

Table 8.4 All the Level-3 materials used in Ranga Reddy district (roofs).

Sl. No.	Description of Level-3 materials: roofing	Remarks
1	Reinforced cement concrete slab	All level-1 materials
2	Reinforced cement concrete plank and joist	Planks and joists from the local building centre
3	Reinforced cement concrete channel	Channels from the local building centre
4	Ferrocement channel	Channels from the local building centre
5	Micro concrete tiles roofing	Micro concrete tiles from the local building centre (level-2) and under-structure – level-1
6	Hybrid slab	All level-1 materials
7	Reinforced cement concrete filler slab	All level-1 materials
8	Stone roofing	Joists from the local building centre
9	Jack-arch roofing	Joists from the local building centre
10	Brick corbel arch	All level-1 materials
11	Brick pyramid	All level-1 materials

Note: All level-3 roofing elements are either made of level-1 materials only or a combination of level-1 and level-2 materials.

The database has been developed from the cost, retention within Ranga Reddy District, embodied energy and CO_2 emission per unit of the Level-1, Level-2 and Level-3 materials and products. The following section will describe how the database for level-1, level-2 and level-3 materials and products were collected in Ranga Reddy district with respect to Jaggamguda.

8.2 UNIT COSTS OF BASIC MATERIALS

The sources of materials such as aggregate, coursed and random rubble stones and wire-cut bricks, clay tiles (level 1) existed within the Ranga Reddy district. Steel, cement, etc., were brought from outside the district. There were local agents and material suppliers who received an agency fee for marketing these. The following table shows how the unit costs of level-1 materials were calculated in the lead chart at Jaggamguda.

Table 8.5 The lead statement of materials at Jaggamguda

Sl. No	Description of the materials	Initial cost	Add seigniorage*	Taxes	Transport cost	loading & unloading	Total unit cost	Unit
1	Cement							
2	sand							

* Seigniorage is a Royal right to a percentage levy. Although the kingship has been abolished in India, the terms still continued. Now this goes to the Government treasury as tax.

A number of feasible walling and roofing systems have been introduced in Ranga Reddy, e.g., micro concrete tiles, reinforced cement concrete plank, joists, channels, ferrocement channels, etc. There were building centres within the district which produced some of the elements shown in Table 8.2. The existing building centre at Aliabad, two kilometres from Jaggamguda, produced door and window frames, etc., and had an adequate infrastructure to produce the pre-cast elements shown in Table 8.2. These building centres were already serving as a source of income generation for the people involved in local construction. However, their turnovers were small because of lack of market demand for the pre-cast elements. It has been assumed that the pre-cast elements shown in Table 8.2 will continue to be produced at Aliabad.

The unit costs of the materials used in Ranga Reddy included their basic costs of production, royalty charges, sales tax and octroi (state customs duty), cost of loading, unloading and transportation. The transportation charges were according to the distance from source to the site and also on the type and condition of roads in the monsoon. The unit costs were calculated based on the Standard Schedule of Rates (SSR, 1996) published by the

Government of Andhra Pradesh, which was updated every year in the month of June. Ranga Reddy district is spread over an area of about 40 kilometre diameter and its roads varied from good quality bitumen topped major district roads to ordinary rural roads without any hard top. In the rainy season the Ordinary Rural Roads were unable to bear the truck load of 12.5 tons and hence, some villages became inaccessible. In general, the transportation cost was exorbitantly high during the entire rainy season. All the material costs shown in this section are inclusive of transportation cost at Jaggamguda site and applicable between October and the first week of June since the rest is rainy season and a lean period for construction. All costs mentioned in Table II.2, Appendix-II are at-site costs, i.e., including transportation, loading, unloading, etc., everything complete.

However, materials brought from outside the district have been excluded from such calculations, since their labour component will generate income elsewhere and beyond the boundary of Ranga Reddy. To study the impact of the use of local materials, the production labour cost of bricks, clay tiles, etc., produced within the district have been separated from the material, equipment, etc. Such separation of costs will enable a decision maker to know if one builds a brick wall in Ranga Reddy, what will be the income generation opportunity for the brick kiln owners and its labourers.

8.3 MONEY RETAINED WITHIN THE DISTRICT FOR THE LOCAL TRADERS AND AGENTS.

It has been mentioned in the last chapter that, according to ILO (1984), small-scale and labour-intensive building-materials manufacturing technologies result in a larger multiplier effect than large-scale, capital-intensive technologies. This matches with the situation in Ranga Reddy district, since the production of bricks, aggregates, etc., were small scale. It is to be noted that the labour components of the level-3 elements (walls and roofs) have been divided into two, on-site and off-site. The labour costs related to all the in-situ process are termed on-site. The same in the production yard including loading and unloading of materials in transportation are termed as off-site. For example, the labour costs for producing one brick till it is delivered at site is considered to be off-site, whereas the construction of a brick wall in cement sand mortar starting from procuring them from the stack until it is cured and complete is on-site. This gives an overall picture of the sum total of labour intensity of a particular level-3 element (walls and roofs).

To examine the impact of local materials at a micro context, it has been assumed that its domain is the district boundary. If a material is produced outside this domain, only the amount of money received by the local traders, who generally act as agents, will be considered as retention. As mentioned above, the materials such as stone chips, coursed and random rubble stones, bricks, clay tiles, etc., already existed in Ranga Reddy for a very long time and act as shelter support to the local private and public buildings. It has been assumed that the pre-cast walling and roofing products from Aliabad building centre will act as a good source of income generation for the people involved in construction in the district. The building centre will ensure good quality of production to compete with the local construction material market and the general level of skills will also be upgraded because of training and supervision.

Retention excludes the cost on construction workers, since that has been added to the labour components of the Level-2 and Level-3 materials. The fuel costs (coal, electricity and diesel) for the production of the local materials including transportation go out of the district boundary since they are all brought from outside. However, the cost of rice husk, fire wood, etc., required for brick and tile burning has been included in retention since they were from the district. Therefore, the net amount of the material cost, after deducting the cost of fuels, etc., brought from outside the district and the production labour, is the retention amount. Therefore, this is the net amount of money that will help the local traders.

8.4 EMBODIED ENERGY AND EMISSION OF CO_2

8.4.1 Embodied Energy for Production

All the construction materials have different unit embodied energies owing to the procurement of different types of raw materials and their transportation to the production centre, and processing and transportation of the finished products to the sites directly or routed through the stockists/ agents, etc. As explained in the last chapter, the embodied energy data from the Energy Directory of Building Materials (1995) by Development Alternatives is the most acceptable one. It had assumed the following.

- The production capacity is medium to small.
- The technology of the production process is based on common practices and adopting energy efficient measures without significantly changing the technology or type of fuel used.

The energy input for each level-1 material is classified into five distinct categories; coal/petrol, electricity, wood, non-wood such as rice husk, and energy from agriculture waste. Sand, soil, stone slabs and coursed and random rubble stones are traditionally quarried manually and hence, production energy has been assumed as zero. The Appendix-I shows the embodied energy of all level-1 materials.

Tiwari (2001) classifies construction materials into three categories according to their energy consumption. According to him, high energy materials are those having embodied energy greater than 5000 Mega Joules per ton, medium energy materials – between 500 and 5000 Mega Joules per ton and low energy materials – less than 500 Mega Joules per ton. Annnexure-I shows that steel, PVC, etc., in India belong to the high energy category.

Most of the building materials production units in Ranga Reddy East were visited several times and data was collected over a period of 18 months. The managers of the production units had systematic databases on fuel consumption required for processing of the finished products that will enable us to calculate the embodied energy and CO_2 emission. The data collection exercise revealed that the sources of the raw materials for a particular product varied widely owing to their locations, e.g., while clay for brick making at Rajbolaram was transported from a distance of six kilometres, the same at Uddamerry village was from ten kilometres away. Therefore, these data were too site-specific and involved laborious calculations before we could use them at a particular site to assess the impacts. A comparison between the energy data collected at Ranga Reddy and the Development Alternatives' data revealed that the energies were comparable for the materials produced in similar manufacturing process. For example, the thermal requirements and electricity consumption for semi-mechanised wire-cut brick production at Rajbolaram was within 5% of the data provided by Development Alternatives. Under such circumstances, their data on finished product has been adopted as embodied production energy and the transportation energy has been used according to the actual distance of the source from the site. This would make the process more general and others can adopt the same process in different contexts.

The environmental impact of the on-site process in Ranga Reddy involved only a very small quantity of diesel (1.2 litres per cubic metre of concrete) for operating the concrete mixing machine and vibrator for consolidation. Apart from that, the site process did not use any other equipment or process which involved energy and emission. This is too small an effect compared to the developed countries, such as, the USA and the New Zealand, where the energy consumed in the production of materials amount to 70% of total construction energy, the remaining 30% being primarily consumed by on-site construction-related activities as cited by UNCHS (1991). UNCHS observed that, in developing countries, this proportion ranges between 90 and 100% as the on-site energy consumption in construction of housing is low owing to rare use of machinery. The situation in Ranga Reddy was similar.

8.4.2 CO_2 Emission for Production

Data on CO_2 emission owing to the building materials production has been a very weak area. Emission data was available only for cement, steel, lime, etc. However, CO_2 emission for aggregates, sand, clay tiles, etc., were not available. This aspect of data collection was the most difficult one and problematic. The author of this dissertation had to move from door to door, find out contacts from the internet and had discussions over telephone, personal interviews, etc. While there is a nationwide concern (at least on paper) on emission, the lack of data in this regard indicates that there is no serious effort towards mitigating this problem. Many workshops and conferences have taken place on sustainability. However, no one provides any data whatsoever on CO_2 emission which will enable an architect, engineer or decision makers to calculate the implications. One of the acceptable documents for calculating embodied energy was the Energy Directory of Building Materials (1995) by Development Alternatives, which did discuss the importance of CO_2 emission but it does not provide any data on it.

NOTES ON SOME DATA ON CO_2 EMISSION

While there is piecemeal information on the CO_2 emission of building material production, there is no document that describes the process of arriving at data. Some researchers, e.g., Bose and Nambier (1995) adopted two alternative fuels; coal and firewood. Bose and Nambier refers to Sedjo (1989) and states that, 30,000 bricks require 25 tons of fire wood, which would emit 26 tons of CO_2, i.e., 0.86 kilograms per brick. Their alternative calculations assume that 1,000 bricks would require 300 kilograms of coal, which is based on Tiwari and Parikh (1994). They adopted 0.75 tons of carbon content in one ton of coal as per Perkins (1974). This would release 17.55 tons of CO_2 (30x0.3x0.75x2.6 = 17.55 tons). It is important to note that the carbon content of coal adopted in this calculation is 75%, which is much higher than that assumed in India. Discussions with researchers of Tata Energy Research Institute revealed that average carbon content of coal as a fuel is 45%-50% and the combustion efficiency is 95%. It is estimated that the Indian brick industry consumes more than 24 million tons of coal annually, in addition to several million tons of biomass fuels (TERI, 2001)

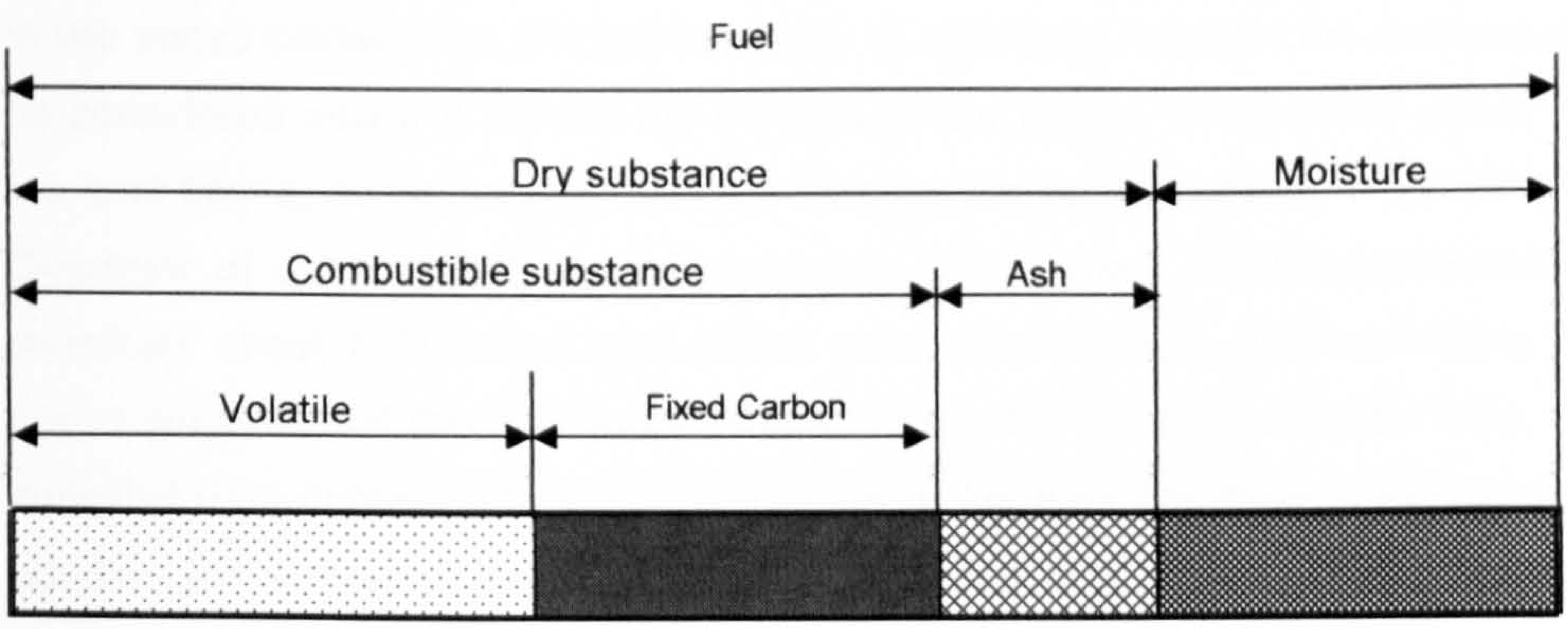
The emission of CO_2 owing to combustion of fuel oil was worked out considering 80% carbon content in the oil by weight and 99% oxidization level of carbon in the oil (TERI, no date). Therefore, one ton of oil burning emits 2.9 tons of CO_2; however, the energy in oil is 10 mega calories per litre, which is much higher than coal or other biomass owing to the high carbon content.

Rice husk and other types of non-wood are used in various manufacturing processes of building materials. It has been mentioned earlier that rice husk is used in Ranga Reddy district for brick manufacturing. Joel (1994) refers to Bowen (1979) to state that the Biomass material contains about 40% carbon by weight, with the remainder hydrogen (6.7%) and oxygen (53.3%). According to the report of Biomass One stop Cleaning House (2003) carbon content of rice husk is 34.58%.

The basis of CO_2 calculation

In view of the absence of direct source of CO_2 emission of all building materials, the researchers of Tata Energy Research Institute, Ministry of Environment and Forest, etc., suggested that the calculation of CO_2 emission may be based on the quantity of carbon based fuels used in the entire process of producing finished building materials. In this context, coal/petrol/diesel, fire wood, non-wood (rice husk), etc., and electricity have been considered. The figure below describes the composition in all fuels, in which only the amount of the different parts vary depending on the specific fuel.

Figure 8-1 The internal distribution of the volatiles, fixed Carbon, ash and moisture of fuels.



Source: Biomass One stop Cleaning House (2003), Chapter 1- P-3.

"Volatile" shown above, is the part of the fuel that is released as a gas and burns with flames. The fixed carbon is the part of the fuel that burns without flame, such as the glowing parts that remains as a fire. The total carbon content, that includes a part of volatiles in the fuels, produces CO_2. If ash and the moisture are taken out of the different fuels, the chemical compositions of the fuels look very much alike.

The Energy Directory of Building Materials (1995) provides the different quantities of energy required (coal/petrol/diesel, fire wood, non-wood, waste and electricity) for the unit production of some materials, e.g., aggregates, cement, steel, etc. The embodied energies are given in kilo Watt hours per unit weight of the materials, which have been calculated after converting the respective fuels to their carbon contents and combustion efficiencies. Therefore, the quantities of equivalent carbon can be calculated after dividing the summation of total energies owing to coal/ petrol, wood, non-wood, etc., by the calorific value of carbon in coal, i.e., 8084 kilocalories/ kilogram (discussion with Tata Energy Research Institute). This will give the total quantity of carbon consumed per unit weight of the material production. The quantity of CO_2 emission has been calculated based on the following chemical reaction.

$$C + O_2 = CO_2$$

Replaced by the molecular weights

$$12 + 16x2 = 44$$

Therefore, 1 kilogram of carbon will create 44/12 kilogram of CO_2

CO_2 generated by the production of unit weight of level 1 materials = energy in kilo Watt hours per unit weight x 860 kilocalories = $\underline{A}$ (say)

CO_2 emission per kg of material = 44/12 x $\underline{A}$ / 8084 kilogram

In the above calculations, the total quantity of electricity input for the material production can be considered only if it is from the thermal power plants. While many power plants in India are coal based, some are hydroelectric and nuclear energy based. According to "An Energy Overview of India" (2002) the hydroelectric, Nuclear and Geothermal/Solar/Wind/Biomass constitute about 25% of the total power generation in India. The remaining 75% are coal-based conventional thermal power plants. This is the average all India data, therefore, CO_2 emission data published by the Government of India for the state of Andhra Pradesh will be adopted for emission calculations. India is divided into five grids of electricity supply, viz., Northern, Southern, Eastern, Western and North-Eastern. Andhra Pradesh comes under the Southern grid. The Government of India's Central Electrical Authority publishes data on CO_2 emission in each zone per unit of electricity produced. According to the "Generation Report" (GOI, 2001-02a), the total electricity in the Southern grid was 130478 Giga watt hours in 2002, which produced 90,808,534 tons of CO_2. Therefore, one kilo Watt hour will emit 695 grams of CO_2.

8.4.3 Non–Renewable Energy and CO_2 Emission for Transportation of Materials from the Outlet to the Site.

It may be recalled that the Development Alternatives' data on unit embodied energy is applicable on the finished building materials at the production site. Carbon-based fuel energy from the same data has been adopted to estimate the CO_2 emission of the materials. This section will discuss the process of calculating additional embodied energy and CO_2 emission owing to transportation of the finished building materials from the production units to the construction sites. The Energy Directory of Building Materials (1995) by Development Alternatives has referred to the Tata Energy Data Directory Yearbook (TEDDY, 1993) to show the energy required for transporting unit weight of materials per unit distance by roads and railways. According to that, a 12.5 tons capacity diesel-operated TATA-truck consumes 0.26 klio Watt hours (thermal) of energy for transporting a ton of materials per kilometre (Energy Directory of Building Materials, 1995, table 3:P1#18). Similarly, it shows that the diesel-operated rail locomotion consumes 39.78 kilocalories per tonne per kilometre of transportation, as shown in the same table-3. Based on these, the data in Table 8.6 has been adopted for calculating the non-renewable energy and CO_2 emission for transportation of the finished building materials from the production unit to the site.

Table 8.6: The basis of embodied energy calculations for transporting materials by rail locomotive and truck.

Transportation energy by diesel operated	**Average energy per ton of material per kilometer**	**Unit of energy**	**Converted to kilo Watt hours**
Rail Locomotive	39.78	kilocalorie	0.046
12.5 tons TATA truck	0.26	kilo Watt hours(thermal)	0.260

Source: Energy Directory of Building Materials, 1995, table-3, page 1#18,)

CO_2 emission per ton of materials transported = by rail per kilometre	$0.046 \times 860 / 8084 \times 44/12 = 0.018$ kilograms
CO_2 emission per ton of materials transported = by 12.5 tons TATA truck per kilometre	$0.26 \times 860 / 8084 \times 44/12 = 0.101$ Kilograms

Based on these, the non-renewable energy and CO_2 emissions have been calculated for different materials. The Appendix –I shows the final quantities of embodied energy and CO_2 emission of different materials.

8.5 LEVEL-1 PRIMARY MANUFACTURE,

The section 8.2 to section 8.4 have explained the basis of calculating unit cost, unit retention of investment on construction, unit embodied energy consumption and emission of CO_2 of the Level 1 materials. All these calculations are with respect to Jaggamguda. In this section the process of the data relating to level-1 materials have been explained.

HARD GRANITE METAL (40 MM), STONE CHIPS 20 MM AND 6 MM

The stone boulders were procured from the local quarries. There were a few crusher houses within the district and all of them had information on the process of production. However, the most systematic data on production was found at AFCONS[1] site at Turkapally. The total amount of electricity consumed per kilogram production of 40 to 6 mm hard granite metal and aggregates was 0.01 kilo Watt hours. This is similar to the Development Alternatives' data (0.0105 kilo Watt hours per kilogram). The unit cost of the materials (40 mm, 20/12 mm and 6 mm) are shown in the Table 8.12. The stone boulders are crushed first and then passed through different gratings to separate out the different categories of the aggregates and then they are put in separate storage bins. Since the entire process involves a common team of skilled workers and helpers, the labour costs could not be attributed to the individual category of aggregates. Therefore, while the unit costs of the three types of aggregates are different, their labour components have been considered to be the same. According to the average data obtained from three crusher houses in Ranga Reddy East, skilled and unskilled workers are 4% and 7% of the total cost respectively. The source of stone dust was the AFCONS crusher house. It is a by-product of aggregate production and hence, the total production energies have already been put on it. Therefore, production energy of stone dust has been assumed to be zero.

RANDOM RUBBLE STONE, COURSED RUBBLE STONE

Random rubble and coursed rubble stones were procured from the quarry at Turkapally village. These two types of stones were the most commonly used material from foundation to the plinth level. Small amounts of energy loss and emission took place during blasting, which was once in fifteen days. At least 1000 cubic metre of stone blocks are quarried in one blasting and hence, its impacts have been ignored. Apart from the blasting, the rest of the process was manual, e.g., quarrying, loading the truck and unloading the stone blocks at site, etc. Therefore, the embodied energy in the material considered is only owing to its transportation from the quarry to the sites. The average unskilled workers' cost was about

[1]AFCONS, a road construction company, was laying the National Highway passing through Ranga Reddy District. They had a crusher house at Tutkapally, which was a major source of stone chips for the adjacent areas.

25% of the total material cost till it reached the construction site. Table 8.12 in the end of this chapter shows the socio-economic and environmental data on random rubble and coursed rubble stone.

40 MM THICK TANDUR STONE

Common people in Andhra Pradesh preferred to use sand stone slabs as flooring materials, named after the places from where they were quarried, e.g., Shahabad, Cuddappa, Tandur, etc. In Ranga Reddy district, Tandur stone was used since that was the closest source (120 kilometres). These stones were either polished or rough and the latter variety was preferred by the common people because of its low cost (half the cost of polished stone). The same stone was used as a roofing material in many buildings also. The labour for quarrying and transporting stone to the site has not been considered in the off-site income generation since it went out of the district. Only the agency charges of 20% of the total cost of the stone till it is delivered at site has been considered as retention. Table 8.12 shows the socio-economic and environmental data on Tandur stone.

SAND FOR MORTAR, SAND FOR FILLING, STONE DUST, SOIL FOR CEMENT STABILISED MUD BLOCK

The fine aggregates used in mortar, concrete and filling plinth were mined from the quarries. The sand from local quarries was very fine and had high silt content, which was not suitable for construction. Medium coarse sand for mortar and coarse sand for concrete works were road transported from Siddipet, which was about 80 kilometres from Ranga Reddy District. Table 8.12 shows the socio-economic and environmental data on different types of sand, stone dust and soil.

WIRE-CUT BRICKS AND CLAY TILES

Wire-cut bricks (230 mm x 115 mm x 75 mm)

It is important to note that almost the entire production of bricks in India is working on coal based technologies. In clamp bond system, 1000 bricks require 400-500 kilograms of coal. Bull's trench kilns require 180-200 kilograms of coal per 1000 (Aslam, 1993). Gujarat alone produces 2 billion bricks per season, which are totally coal-based (Oza, 1993).

It has been already mentioned that the quality of clamp bond bricks produced in Ranga Reddy was poor. In 1995-96, there was only one semi-mechanised brick production unit in Rajbolaram[2] that manufactured wire-cut bricks with river bank clay. The plant had a single

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[2] Data collected on the 18th May, 1996, Saturday from the brick kiln at Rajbolaram, a village situated at a distance of 7 kilometres from the Government administrative office, Ranga Reddy district.

deck extruder with a capacity of 1,250 bricks per hour resulting in 10,000 bricks per day. The clay column extruded through the die was cut into bricks by hand operated cutter. Bricks were air dried in a shed, arranged in stacks and then finally fed to the high draught kiln. The kiln was a top-fed, rice husk fired continuous production unit in which fire followed a linear path. Following is the data on brick production at Rajbolaram.

- 10,000 bricks per stack was burnt for 72 hours and cooled for 24 hours.
- Half truck i.e., 3 cubic metre of rice husk weighing 5 tons was carried from a distance of 10 kilometres.
- The clay for brick making was obtained from a local river about 6 kilometres from the kiln.
- The total direct labour input for the production of 10,000 bricks per day was as follows
    - Skilled worker = 6, i.e., 0.0006 working days/ brick
    - Unskilled worker = 26, i.e., 0.0026 working days/ brick

The labour involvement in brick production at Rajbolaram was very close to the data provided by the National Research Development Corporation, India, (NRDC, 2003). According to their data, the manpower requirements for the production of 30,000 bricks per day are as follows.

Skilled workers	= 20 working days
Unskilled workers	= 85 working days

Direct manpower per brick

Skilled worker	= 20/30000	= 0.0007 working days
Unskilled worker	= 85/30000	= 0.0028 working days

The above data is very close to that of Ranga Reddy. In this section the National Research Development Corporation's data on manpower requirements for brick production has been adopted and the following calculations based on 1996 data indicate the extent of income generation in Ranga Reddy district.

Daily wages according to the Standard Schedule of Rates (SSR, 1996). (Rs.80 = £1)

Skilled worker	= Rs. 71.5 / day x 0.0007 working days = Rs. 0.050 / brick
Unskilled worker	= Rs.37.8 / day x 0.0028 working days = Rs. 0.106 / brick

Brick price in 1996 was Rs.1.3 (£0.016) per piece, out of which, 4% and 8% respectively were the skilled and unskilled workers' cost. Therefore, the total income generation was 12% of the cost of brick. The semi-mechanised brick production was less income-generating than the manually-operated clamp bond method, e.g., according to SKAT (1990:97), 22.3% of brick production cost in Bangladesh was on manpower.

It may be noted that, although rice husk was used as fuel in Rajbolaram, the general trend in India is to use coal and/or firewood for brick production, which has been the basis for energy calculation in the Development Alternative's data. The total thermal energy for production between Development Alternative's data and the Rajbolaram data will not vary much because both used standard machinery. Therefore, the embodied energy owing to coal/petrol (1.0674 kilo Watt hours per brick) and fire wood (0.327 kilo Watt hours per brick) may be assumed to be generated by burning rice husk. Therefore, the total thermal energy of 1.394 kilo Watt hours (5.01 MJ) per brick will be owing to burning agriculture waste. These two alternatives will be used while calculating the impact assessment. It may be noted that there are efforts towards reducing CO_2 emission and embodied energy in brick production. The Vertical Shaft Brick Kiln technology, in its introduction stage in India, already demonstrated a potential savings of 120 tonnes of CO_2 per million bricks produced. (Kumar et al, 2000). However, this method is yet to gain popularity.

CLAY TILES (250 MM X350 MM)

Clay tile was introduced in India in 1864 (Gupta, 1998). The industry was introduced by the Basel Mission Pioneers in Mangalore, India. Popularly it is called Mangalore tile. The size of the tiles vary from region to region, however, the most commonly available dimensions are 250 mm x 350 mm. The socio-economic and environmental data of clay tile is shown in Table 8.12 based on the Energy Directory of Building Materials (1995).

Lime and Cement

Both lime and cement were brought from outside Ranga Reddy district. They had two different sources of CO_2 emissions during cement and lime production. Combustion of fossil fuel to operate the production process in the kilns is a large source. The chemical process of calcining lime stone into lime also produces CO_2. Therefore, both for cement and lime, CO_2 emission owing to calcinations of lime stone is as important as the fossil fuel burning. The type of fuel and energy input has been shown in Table I.4 of Appendix I.

Lime

Based on Development Alternatives' data, the CO_2 emission for lime production has been calculated to be 0.552 tons per ton of lime production. According to the Government of India's (GOI, 2004: 42) Green House Gas Inventory Information, CO_2 emission can be calculated from the following formula; Emission factors = Fraction of CaO content in clinker * 0.7848 + Fraction of MgO content in clinker * 1.0915 * (1+ Cement clinker to dust losses from the plant)

Since we are calculating the CO_2 emission owing to CaO production we may reduce the expression as follows;

Emission factors = 0.7848, i.e., 1 tonne of CaO will produce 0.785 tonnes of CO_2 (ignoring the MgO content)

Therefore, for the production of lime, 0.552 tons of CO_2 will be produced for the fossil fuel burning and 0.785 tons will be for the calcinations, which makes a total of 1.337 tonnes. Since these were brought from outside the district, the off-site labour does not apply for retention calculation. Lime was transported from the source to the building material suppliers in Ranga Reddy from where it was transported to the sites. In this process the material transportation over 120 kilometres was by 12.5 tons TATA truck and by road. The socio-economic and environmental data of lime is shown in Table 8.12.

Cement

The Indian cement industry is about 85 years old and is the third largest producer in the world. The production capacity of various plants varies from ten tons per day to 6,000 tons per day (TERI, no date). Ordinary Portland cement is a major part of the total cement production in India, which could be attributed to its traditional usage in building industry. The total CO_2 emissions of the cement sector has increased by about 2.4 times from 1981-82 to 1994-95 on account of increased sectoral activity (TERI, no date).

The CO_2 emissions have declined from 1.16 in 1981-82 to 1.00 tons/ton of cement production in 1994-95 largely owing to the commissioning of many dry process plants of over one million ton capacity (TERI, no date-a). According to a report of THE CEMENT MANUFACTURERS' ASSOCIATION (no date) on the Indian Cement Industry, total CO_2 emissions per ton of cement (assuming a 0.95: 1 clinker to cement ratio) ranges about from 0.85 to 1.15 ton, say one ton. These sources do not explicitly discuss the CO_2 emission owing to lime stone calcinations.

Development Alternatives' data provides the break up of coal/petrol, electricity, fire-wood and non-wood (rice husk) required for one kilogram of cement production. All these data are provided in kilo Watt hours, which means that the carbon content and oxidation efficiency of the respective fuels have been considered and accordingly the net energy has been calculated. According to Development Alternatives' data (Energy Directory of Building Materials, 1995), the electrical energy for cement production is 120-155 kilo Watt hours per tonne and fuel consumption per kilogram of clinker is 950 kilocalories (1.105 kilo Watt hours). The report by National Council for Cement and Building Materials (NCCBM, 2002-03) states that the improved production technology has reduced the embodied energy of cement and the revised data are 734 kilocalories (0.853 kilo Watt hours) of fuel per kilogram of clinker and 0.084 kilo Watt hours per kilogram of cement production. This (NCCBM, 2002-3) being the latest data, has been adopted for calculating embodied energy of cement. The following Table 8.7 and Table 8.8 show the break-up of energy input in 1994 and 2002-2003.

Table 8.7: The energy consumption per kilogram of cement including quarrying, production and transportation according to Energy Directory of Building Materials, 1995.

Category	Petrol/Coal	Electrical	Miscellaneous	total kilo Watt hours/kilogram
Quarry	0.0156		0.00008	0.0157
Production	**1.076**	**0.324**		1.4000
Transportation	0.183			0.1830
Total kilo Watt hours/kg	1.2746	0.324	0.00008	1.5987

Note : The shaded box shows the consumption of petrol/coal and electricity in production of cement are 1.076 and 0.324 kilo Watt hours respectively.

Table 8.8 The energy consumption per kilogram of cement including quarrying, production and transportation according to NCCBM (2002:03)

Category	Petrol/ Coal	Electrical	Miscellaneous	total kilo Watt hours per kilogram
Quarry	0.0156		0.00008	0.0157
Production	**0.8535**	**0.084**		0.9375
Transportation	0.1830			0.1830
Total kilo Watt hours per kilogram	1.0521	0.084	0.00008	1.1362

Note : The shaded box above shows the consumption of petrol/coal and electricity in production of cement which have reduced compared to the data shown in the shaded box of Table 8.7.

Table 8.8 shows that the embodied energy of cement has been taken as 1.1362 kilo Watt hours per kilogram. The same data will be adopted for calculating CO_2 emission and non-renewable embodied energy. The emission owing to calcinations of $CaCO_3$ has been adopted from the Government of India's (GOI, 2004) Green House Gas Inventory Information. According to the latter's estimation, the weighted average emission factor for the cement industry in India is in the range of 0.534 to 0.539 tonnes per tonne of cement clinker. In this dissertation an average value 0.537 tonnes per ton of cement in the process of calcinations of lime stone ($CaCO_3$) has been adopted. If we compare this with that of the United States of America, CO_2 emission owing to fossil fuel burning and limestone ($CaCO_3$) calcinations are 0.75 tonnes and 0.5 tonnes respectively (BuildingGreen.com, 1993:7). Therefore, the total emission of CO_2 in India is 1.01 tonnes per tonne of cement (Table I.4 of Appendix I) , compared to 1.25 tonne in USA. This data has been adopted in this dissertation since the other sources of data do not explicitly mention this aspect of CO_2 emission of cement.

In Ranga Reddy, cement was procured from a mini cement plant about 100 kilometres from Hyderabad, and transported to the main distributor at Hyderabad by 12.5 tons TATA truck. From there, it was transported to the site as and when ordered by the local agent at Ranga

Raddy. The total distance covered by 12.5 tons TATA truck was 135 kilometres. For the retention calculation, only the agency charge of 15% of the total cost of cement has been considered. Since these were brought from outside the district, the off-site labour does not apply in the retention calculation. The socio-economic and environmental data of cement is shown in Table 8.12.

REINFORCING STEEL, STRUCTURAL STEEL, BINDING WIRE

According to Shastri (2003), the global production of steel is 780 million tons and it emits approximately 356 million tons of CO_2 globally from the cradle to the gate. Indian iron & steel industry is the 9th largest producer (28.8 million tons in 2002) (Shastri, 2003). According to the Organisation for Economic Co-operation and Development (OECD, 2001), iron and steel industry is the largest energy consuming manufacturing sector in the world. In 1990, its global energy consumption was estimated to be 18-19 Exa Joules , or 10-15% of total annual industrial energy consumption. The associated CO_2 emissions are estimated to be 1425 million tons. In 1995 this amount increased to 1442 million tons CO_2, equalling about 7% of global anthropogenic CO_2 emissions (OECD, 2000).

Shastri (2003) refers to Phylipsen (2000) to state that the CO_2 emission per ton of crude steel production ranges between 1.4 - 3.7 tons. He states that emission of CO_2 at the Steel Authority of India Limited is 3.4 tons per ton of steel whereas TATA steel emits 2.66 tons per ton of crude steel. According to the Development Alternatives' data, one ton of structural steel and reinforcing rods emit 3.8 tons and 3.2 tons of CO_2 respectively, which is very close to the Steel Authority of India's data.

In Ranga Reddy, structural steel and reinforcing rods were procured from a mini steel plant that was about 100 kilometres from Hyderabad. By means of 12.5 tons TATA truck steel was transported to the main distributor at Hyderabad from there it was transported to the site as and when order was placed by the local agent at Ranga Reddy. The total distance covered by road was 135 kilometres. For retention calculation only the agency charges of 15% of the total cost of has been considered. Binding rods were also from a similar distance and hence, the same data has been adopted for it. The socio-economic and environmental data of steel is shown in Table 8.12.

WOODEN SHUTTERING AND SCAFFOLDING, TIMBER FOR STRUCTURAL USE

Wood plays three roles in the forest sector carbon cycle, viz., a physical pool of carbon, substitute for more energy intensive materials, and a raw material to generate energy. Wood removed from a forest by harvest can be viewed as a replacement for natural mortality (IPCC, 2001) (albeit at faster rate). Even when converted to products, they continue to hold captive large volume of carbons in their cells (Sedjo, 2001). The issue, however, is whether one should consider the embodied carbon present in timber while calculating the impact on environment. If timber is used in a building as flooring, doors, windows, shelves, interior decoration elements, etc., a large amount of embodied carbon will continue to exist in the entire life cycle of the building. In the end it may be disposed off to a paper factory or similar use. Since this carbon will not emit CO_2, this aspect has not been considered in this section.

Let us now examine the impact of wooden shuttering materials for roof slab casting and wooden scaffolding used in general construction. The field experience in Ranga Reddy district revealed that shuttering materials could at best be used five times for concrete casting provided that it is of good quality and the maintenance is regular. While implementing the DFID funded Orissa health project in 1999, the contractors reported that the poor quality jungle wooden shuttering could not be used more than twice for casting reinforced cement concrete slab, which was probably owing to their reluctance in maintaining them.

Figure 8-2 The huge amount of local wood used for the sun-shade casting at Panasapada under the DFID funded Orissa Health Project.

Source: Author

In Itamati district of Orissa, steel shuttering was available and hence, it was used in roof casting. These shuttering materials were taken from the state Government's Infrastructure Development Corporation. According to their record book it was the 89th casting (in 1999) by the steel shuttering materials and its condition was so good that it could bear the wear and tear of many more castings.

Similarly, the wooden scaffolding could be used for two buildings of 100 square metre each, whereas steel props could be used for about 100 buildings, if not more. Therefore, steel shuttering and scaffolding appear to be more cost effective in terms of their life cycle use. However, this dissertation adopts wooden shutter and scaffolding for impact assessment because of their wide use across the country. It is important to note that illegal procurement of jungle wood for scaffolding and shutter is very common at village level. In this process, timber is being depleted and hence, its impact needs to be assessed.

Wood for Shuttering:

Shuttering is required for in-situ casting, e.g., reinforced cement concrete roof. A surface is created on which reinforcing bars are placed according to structural design and then cement concrete is cast on it, compacted and then cured for at least two weeks before the slab is de-shuttered. 19 mm thick wooden shuttering was generally used in Ranga Reddy district. These shutters were supported by Eucalyptus poles of about 75-100 mm diameter. Procurement of the eucalyptus poles of 100 mm diameter, i.e., felling, cutting to size, etc., were all done manually. The embodied renewable energy and the non-renewable energy and CO_2 emission owing to the transportation of the wood from the jungle to the contactors' store and then from there to the site and back have been considered in this section. At site, the poles are manually tied with handmade ropes. The total weight of wood was 95 kilogram per square metre and it is assumed to be used for casting a slab five times.

Scaffolding

Scaffolding is required in any construction activity where the work location is higher than the convenient reach and movement of the masons, e.g., masonry walls, painting, plastering, etc., beyond 1500 mm height from floor or ground level. Eucalyptus poles of 75-100 mm diameter were used as scaffolding. The making of scaffolding work was also a manual job and hence, the small amount of embodied energy and CO_2 emission owing to the transportation has been considered. For determining the quantity of wood required in scaffolding, it has been assumed that;

- for constructing 100 square metres of floor area, 30,000 bricks are required (Rai , Jaisingh, 1986). According to the analysis of rates of the Panchayati Raj Engineering Department, one cubic meter of brickwork consumes 480 bricks. Therefore, 100 square metre of floor area will have 62.5 cubic metre of brickwork in it. Calculations (Appendix I) show that a total of 463 kilograms of wood is required to make the scaffolding complete, which could be used for construction of two buildings each having 100 square metre of covered area.

Wood materials have advantages of having relatively small energy requirements in their production and thus carbon emissions associated with their production is modest (Sedjo, 2001). For doors, shuttering and scaffolding, the embodied energy has been calculated under the head 'renewable wood' based on the Energy Directory of Building Materials (1995).

RUBBER BASED WATERPROOFING COMPOUND.

Rubber based waterproofing compound is used in concreting and rooftop plastering. The percentage of this is 0.2% (by weight) of the cement used in mortar or concrete. Data on rubber-based waterproofing compound in the Indian context was not available. From the internet, data on rubber and natural latex provided by Alcorn (1998) was found to be 67.5 Mega Joules per kilogram in the context of New Zealand. It may be noted that Alcorn's data on steel, cement, etc., were comparable with that of the Indian database. Therefore, Alcorn's data has been adopted in this dissertation.

DIESEL

The use of diesel in construction is primarily for the transportation of all materials from level-1 to level- 3 – from raw materials till the finished product reaches the site. Embodied energy and CO_2 emission of each material in this context have been calculated according to Tata Energy Data Directory Yearbook (TEDDY, 1993). In addition to transportation, only a very small amount of diesel is required for operating concrete mixing and compaction (1.2 litres/ cubic metre). In Ranga Reddy, diesel was brought from a refinery in Maharashtra, 651 kilometres from Hyderabad, by rail locomotive. From Hyderabad it was road transported by diesel operated TATA truck (35 kilometres) to Ranga Reddy. The following is the basis of embodied energy and CO_2 emission calculation per litre of diesel used at Jaggamguda site to operate concrete mixing machine and vibrator. The production energy of diesel has been excluded owing to the lack of reliable data. The following has been referred to while calculating embodied energy of diesel.

Density of diesel 960 kilogram/cubic metre	IS 875 (Part-1) – 1987
Carbon content = 80%	(TERI, no date).
Combustion efficiency = 99%	(TERI, no date).

Distance covered by Rail locomotive
= 651 kilometres
Distance covered by TATA Truck
= 35 kilometres

8.6 LEVEL-2 SECONDARY PROCESSING-

Based on level-1 materials

All the pre-cast elements could be produced at site, if the quantity of production is more than the break even point. According to the Andhra Pradesh Primary Education Project experience, the onsite manufacturing of a particular pre-cast element will be economically viable only if at least ten classrooms (36 square metre each) could be constructed using that element. In Andhra Pradesh Primary Education Project, most of the pre-cast elements were introduced for the first time and hence, an on-site production process was adopted. However, to make it cost effective, production sites were located at the load centre of requirements, e.g. a village named Kokapet was chosen for micro concrete tile production since that was more or less centrally located with respect to the other sites where the same roofing system was adopted. It is to be noted that the availability of electricity, water and condition of roads also are be considered while selecting a site for pre-casting.

If there is an adequate market demand, all the level-2 materials should ideally be produced in a building centre for the ease of quality control. It will also be a permanent institution for employing the local people. As mentioned before, it has been assumed that the pre-cast production unit at Aliabad would turn out to be the source of all the level-2 products under consideration. The distance between Jaggamguda and Aliabad is two kilometres, which does not make any difference in the cost of transportation from the source to the site, which is charged in steps of five kilometres. Similarly the variation in embodied energy and emission for the reduction of two kilometre distance will be low, e.g. for the transportation of stone chips from the quarry to Aliabad embodied energy will be reduced by 0.6%. Therefore, the lead chart of level-1 materials for Jaggamguda has been assumed to be valid for Aliabad also. However, the cost and energy for transportation of the finished pre-cast elements from Aliabad to Jaggamguda have been considered including the loading of the pre-cast materials at the building centre and unloading at site. In Andhra Pradesh Primary Education Project, loading and unloading were done manually and hence, are labour-intensive. It is important to note that, if the distance between a site and a building centre is more than five kilometres, a separate lead chart should be prepared and linked up with the analysis of rates of the level-1 materials.

The analysis of rates approved by the Government of Andhra Pradesh was the basis of calculating socio-economic and environmental impacts of each level-2 technology. For calculating the impacts of transportation involving diesel, data from Tata Energy Data Directory Yearbook (TEDDY, 1993) on the road transportation has been adopted. The heat energy and specific gravity of diesel have been assumed 10,625 kilocalories per kilogram (Energy Directory of Building Materials, 1995) and 0.96 (IS 875 (Part-1) – 1987) respectively.

About 0.55 litres of diesel is required for transporting 12.5 tons of pre-cast elements over 2 kilometres. The corresponding 1996 rate of diesel (SSR, 1996) has been adopted to calculate the transportation cost.

The level-2 materials have been divided into walling and roofing elements and the following section will describe them. Before we embark on detail analysis, let us first look at Table 8.9 which refers to the respective Appendix for detailed information on the different walling and roofing systems.

Table 8.9 The pre-cast walling and roofing elements assumed to be produced at Aliabad.

Level-2 component	Description	Appendix and page number
Walling systems		
Cement stabilised mud block (5% stabilization)	Cement stabilised mud block is made by compacting a mixture of soil and cement (5%) in a block making machine that is usually 100% manually operated.	Appendix III page number xvii
Interlocking cement stabilised mud block (10% stabilization)	An interlocking cement stabilised mud block is made by compacting mixture of soil and cement (10%) in a block making machine that is usually 100% manually operated	Appendix III page number xxi
Stone concrete blocks	Stone concrete blocks are made up of lean concrete mix of cement: sand : coarse aggregate; 1:3:6, 1:4:7 or 1:5:8	Appendix III page number xxiv
Roofing systems		
Reinforced cement concrete joists	Pre-cast reinforced cement concrete joists are beams with small sections. These are supported on beams or walls. The joists support the planks.	Appendix IV page number xxxii
Reinforced cement concrete planks	The planks are small reinforced cement concrete slabs. These are placed between the joists and the gaps between the planks are filled with concrete to form a roof or intermediate floor.	Appendix IV page number xxxi
Reinforced cement concrete channels	Pre-cast reinforced cement concrete channel is a trough section cast in reinforced cement concrete and formed on a ground mould. After adequate curing, it is lifted and placed between the walls or beams to make a roof or intermediate slab	Appendix IV page number xxxvii
Ferrocement channels	A pre-cast ferrocement channel is a light weight roofing element, which is made of 1:2 cement and sand mortar and mild steel reinforcement The casting of ferrocement channel is done on a ground mould, then it is cured and lifted in position to make a roof.	Appendix IV page number xli
Micro concrete tile	Micro-concrete tiles are made of plain cement concrete using small stone chips (maximum size not more than 5 mm) and hence, it is called micro concrete.	Appendix IV page number xliv

Source: Based on Appendix III and Appendix IV

8.6.1 Walling elements: Cement Stabilised Mud Block, Interlocking Cement Stabilized Mud Block (10%) and Stone Concrete Blocks

These three types of building products were used in masonry wall construction. Cement stabilised mud block was produced with 5% cement. The interlocking cement stabilised mud block was produced with 10% cement. All the blocks have been assumed to be from the building centre at Aliabad, which was about 2 kilometres from Jaggamguda. The following Table 8.10 shows the important aspects of the walling elements (level-2).

Table 8.10 The basic information on the pre-cast walling blocks

Description of the pre-cast blocks	Dimensions	Dry weight per block (kilogram)	Wall thickness (mm)
Cement Stabilised Mud Block (5% stabilization)	230 x 108 x 76	3.6	230
Interlocking Cement Stabilised Mud Block (10% stabilization)	300 x 150 x 100	7.5	150
Stone concrete blocks	290x 190 x 140	18.8	190

Source: From Appendix III

The costing detail of these three walling blocks has been shown in Appendix III, which has been divided into material and labour costs. The labour components have further been divided into on-site and off-site, which has already been explained. Money retained within the community is the net amount after deducting production labour and fuels which are brought from outside the district. Table 8.12 shows the socio-economic data calculated with respect to Jaggamguda.

8.6.2 Roofing elements: Pre-cast Reinforced Cement Concrete Planks, Joists, Channels, Ferrocement Channels and Micro Concrete Tiles

These roofing systems (level-2) have been assumed to be produced in the same building centre at Aliabad. Out of these, reinforced cement concrete and ferrocement channel units could span over 5.5 metre wide classrooms. The economic span of a pre-cast reinforced cement concrete joist is 2.7 metres. The joists were placed between the wall and the intermediate beam with a spacing of 1200 mm -1500 mm centre to centre. The gaps were bridged with pre-cast reinforced cement concrete planks, brick arches or stone plates to make plank and joist, jack-arch or stone roofing. The following table shows the important information about the roofing elements.

Table 8.11 The basic information on the pre-cast roofing elements.

Description of the pre-cast blocks	Dimensions (in mm)	Dry weight (kilogram)
Reinforced Cement Concrete Planks	300 x 60 x 1500 length	54.35
Reinforced Cement Concrete Joists	150 x 150 x 2470 length	135.87
Reinforced Cement Concrete Channels	295x 130 x (25 thick) x 3600 length	142.66
Ferrocement Channels	500X 25 x 6500 length	424.03
Micro Concrete Tile	230 x 8 x 400	2.3

Source: Calculations based on Appendix IV

The unit weights of the roofing elements in the above table show that ferrocement channel roofing unit had the highest weight. Ferrocement channels were lifted to position by manual labour and hence, the load carrying capacity of the construction workers needed attention. Although a railway porter can carry 40 kilograms of weight, the same does not apply in a situation where a group would lift a heavy element such as ferrocement channel. According to the field experience of Andhra Pradesh Primary Education Project, it may be assumed that each labourer can lift 25 kilograms safely. Therefore, 16 labourers were engaged for loading and unloading the ferrocement channels. The time and motion study of Andhra Pradesh Primary Education Project revealed that each channel required about 20 minutes for loading and about the same time for unloading and stacking, i.e., 1.33 working days. Similarly, reinforced cement concrete joists and channels required a team of 6 labourers and they took 20 minutes for loading and unloading, resulting in 0.25 working days per unit. Similarly planks would require 0.08 working days per unit.

This chapter has described the process of data collection from different sources and why a particular one was adopted in this dissertation. Many technical discussions with the institutes, individuals and the Ministry, as mentioned in this chapter, helped in working out the final set of data as shown in Table 8.12. It is important to note that the data in the table is just acceptable, since some of the energy data are not from Indian sources. There was a consensus among the research institutes and the individual researchers that there should be a complete energy handbook for the building industry. The next chapter deals with the complete walling and roof systems to form the suitable database for impact assessment.

Table 8.12 Lead statement for construction of primary school buildings at Jaggamguda, Ranga Reddy, according to Standard Schedule of Rates for the year 1995-96 with effect from 01-07-1995-1996, Government of Andhra Pradesh (Rs.80 = £1).

SL.NO	Material	Distance from source	Rate	Unit	Money retained	Non-renewable	Renewable	Waste	CO_2	Cost → coal/diesel /electricity	Skilled worker	Unskilled worker
											Multiply this factor by the value in the column "Rate"	
		Km	Rs		Rest	Mega Joules	Mega Joules	Mega Joules	Kg	Rs		
1	20 mm hard granite metal/ cubic metre	12.00	411.50	/cubic metre	245.51	547.7210	0.0000	0.2416	66.6312	120.73	0.04	0.07
2	6mm hard granite stone chips	12.00	246.90	/cubic metre	99.01	547.7210	0.0000	0.2416	66.6312	120.73	0.04	0.07
3	40mm hard granite metal	12.00	278.40	/cubic metre	127.05	547.7210	0.0000	0.2416	66.6312	120.73	0.04	0.07
4	Random rubble stone	8.00	148.65	/cubic metre	111.10	17.9452	0.0000	0.0000	1.9472	7.82	0	0.2
5	Coursed rubble stone	8.00	281.75	/cubic metre	203.49	17.9452	0.0000	0.0000	1.9472	7.82	0	0.25
6	Sand for mortar	80.00	264.70	/cubic metre	39.71	137.5802	0.0000	0.0000	14.9288	15	% As agency charges	
7	Sand for filling	10.00	148.65	/cubic metre	111.43	17.1975	0.0000	0.0000	1.8661	7.49	0	0.2
8	Stone dust	12.00	132.35	/cubic metre	91.77	20.6370	0.0000	0.0000	2.2393	7.49	0	0.25
9	Bricks coal based	8.00	0.88	/no	0.74	3.8647	1.1737	0.0000	0.5475	0.02	0.0569	0.08
10	Wirecut bricks- rice husk	8.00	1.30	/no	1.13	0.0277	0.0000	5.0108	0.5475	0.02	0.0385	0.0814
11	40mm thick Tandur stone	120.00	45.00	/sqm	9.00	11.6644	0.0000	0.0000	1.2657	20	% As agency charges	
12	Lime	120.00	3.00	/kg	0.75	5.1992	0.0000	0.0002	1.3492	25	% As agency charges	
13	Cement	135.00	2.28	/ kg	0.34	4.2102	0.0000	0.0003	1.0195	15	% As agency charges	
14	Steel reinforcement	135.00	17.20	/kg	2.58	30.362	0.000	0.000	3.572	15	% As agency charges	
15	Steel structural	135.00	20.00	/kg	3.00	36.3186	0.0000	0.0000	4.2038	15	% As agency charges	
16	Binding wire	135.00	25.00	/kg	3.75	30.3620	0.0000	0.0000	3.5721	15	% As agency charges	
17	Clay tiles	8.00	3.50	/no	2.57	0.2899	3.9129	3.6325	0.8731	0.23	0.04	0.16

18	Soil for Cement Stabilised Mud Block	15.00	150.00	/cubic metre	103.70	20.1884	0.0000	0.0000	2.1906	8.80	0	0.25
19	Wooden shuttering	35.00	73.75	/sqm	54.21	4.0794	108.3261	1.8549	0.9251	3.10	0.13	0.10
20	Wooden scaffolding	20.00	23.32	/cubic metre	9.08	0.1384	69.6179	0.0000	0.0150	0.06	0	0.61
21	Rubber based waterproofing compound	135.00	25.00	/kg	2.50	67.63	0.00	0.00	7.34	10	% As agency charges	
22	Enamel paint	135.00	80.00	/litre	8.00	86.905	0.000	0.000	9.430	10	% As agency charges	
23	Bitumen	135.00	7.00	/kg	0.70	44.226	0.000	0.000	4.799	10	% As agency charges	
24	100 PVC pipe 2.39 kg/	35.00	49.21	/m	4.92	369.83	0.00	0.00	48.15	10	% As agency charges	
25	Polythene sheet 1.5mm thick	135.00	44.00	/sqm	4.40	137.88	0.00	0.00	14.96	10	% As agency charges	
26	Timber door	35.00	1000.00	/sqm	731.49	289.565	260.371	9.275	33.833	38.51	0.15	0.08
	Timber for structural use	35.00	10000.00	/cubic metre	8153.67	194.070	1548.034	97.627	46.449	146.33	0.12	0.05
27	Eucalyptus poles	20.00	2.35	/kg	1.13	0.000	5.233	0.000	0.000	0.05	0	0.5
28	Latex based waterproofing for mixing with cement	135.00	118.00	/kg	11.80	67.50	0.00	0.00	0.00	10	% As agency charges	
29	Latex based waterproofing for mixing with water	135.00	345.00	/kg	34.50	67.50	0.00	0.00	0.00	10	% As agency charges	
30	Diesel/litre	960.00	15.00		1.50	44.55	0.00	0.00	2.80	10	% As agency charges	

Source: Based on the analysis shown in this section and SSR (1996).

Special note: The present rates of cement and reinforcing steel in Andhra Pradesh (SSR, 2005) are Rs.4.4 (£0.055)/ kilogram and Rs.27 (£0.34)/ kilogram respectively. Therefore, the cost of cement and steel in 2005 has increased by 193% and 157% with respect to that of 1996. The rates of 1996 were adopted to show the life cycle impacts.

CHAPTER 9 DATABASE FOR IMPACT ASSESSMENT: LEVEL-3

9.1 LEVEL-3 -TERTIARY FABRICATION – WALLS AND ROOFS

Level-3 products consist of 6 types of walling and 11 types of roofing systems, which have inputs from level-2 and level-1 materials, described in the last chapter. While some of the roofing and walling systems are pre-cast element intensive, the others are primarily based on conventional materials and are in-situ process oriented. Let us now discuss walling and roofing separately.

9.2 WALLING SYSTEMS

Each walling system discussed here has been divided into two parts, viz., the basic structure and finishing. The type of finishing on a wall depends upon the strength and endurance of the basic building blocks, e.g., brick, stone blocks, etc. A masonry wall with medium quality bricks (50 kilogram per square centimetre) needs plastering and painting, whereas in a rat-trap wall in cement sand mortar, pointing would be adequate since bricks of at least 75 kilogram per square centimetre strength are used. Let us first discuss the basic structure.

9.2.1 Basic Structure

Basic structure here means only the structural components of the wall, e.g., in the case of stone concrete block masonry, it would mean the blocks, 1:6 cement mortar, labour, scaffolding, etc. It does not include any finishing such as pointing, plastering, etc. The walling systems have been divided into group-1 and group-2. The group-1 is based on conventional materials, viz., brick and coursed rubble stone walls. All these technologies have been explained in the Appendix III. The group-2 walling systems are based on pre-cast elements. Let us first discuss the group-1 systems.

<u>WALLING GROUP-1</u>

Group 1 walling systems consist of the following.

- 230 mm thick solid brick masonry using wire-cut bricks in 1:6 cement sand mortar,
- 230 mm thick rat-trap using wire-cut bricks in 1:6 cement sand mortar,
- 380 mm thick coursed rubble stone masonry in 1:6 cement sand mortar.

Let us first discuss the structural aspects of the walling systems without finishing items. Ranga Reddy district had many clamp bond brick fields, which produced very poor quality bricks. These bricks would barely pass the minimum standard (35 kilogram per square centimetre) set by the Bureau of Indian Standards (IS-1905, 1980). It is important to note that the Government engineering department has been indirectly encouraging the production of such poor quality bricks by recommending an increased wall thickness of 345 mm to make it structurally safe. When the Andhra Pradesh Primary Education Project team conducted a resource mapping exercise, they identified a wire-cut brick production unit at Rajbolaram village in Ranga Reddy East which produced bricks of average strength of more than 75 kilogram per square centimetre. With Rajbolaram bricks one could make a structurally sound 230 mm thick masonry wall cheaper and perhaps more durable than the conventional 345 mm thick masonry wall.

The traditional shelter in Ranga Reddy is local materials based, e.g., stone masonry wall and foundation. Random rubble stone was cheap, however, its irregular shape resulted in a minimum wall thickness of 450 mm. Although coursed rubble stones were more expensive than the random rubble, because of the additional labour charge for stone dressing, one could make 380 mm thick masonry wall with this type of stone. A 380 mm wall thickness not only saved on volume, but also increased the size of internal space for any given covered area.

Despite the fact that the clamp bond bricks were of poor quality, their availability and perhaps ease of handling made their use popular. However, the community was very well aware of their poor quality and hence, never used clamp bond brick in the foundation. The trend of constructing stone wall, though at a slower pace, was still continuing in the district.

WALLING GROUP - 2

The group-2 walling systems consist of the following.

- 190 mm thick stone concrete block masonry in 1:6 cement sand mortar
- 230 mm thick cement stabilised (5%) mud block masonry wall in 1:4:8 cement fine sand and mud mortar.
- 150 mm thick interlocking cement stabilised (10%) mud block masonry in 1:6 cement sand mortar

The above three walling systems have different thicknesses and hence, different thermal properties, which control the indoor comfort conditions. Thin walls, such as in interlocking cement stabilised mud block, are not as comfortable as 230 mm thick brick wall, especially in the Indian summer months. However, this section focuses on the nine socio-economic and environmental parameters and the impact assessment will be on the basis of unit elevation area of the walls. Factors such as light, ventilation, thermal comfort, etc., have been excluded from the scope of this dissertation.

9.2.2 Finishes on Walls

In this section the unit cost of a walling system has been treated as a complete product including their basic structural cost, external and internal finishes. The finishing method and materials vary from technology to technology. For example, external surface of rat-trap walls have been found to perform well with 1:3 cement sand pointing; however, it needs brick strength of at least 75 kilograms per square centimetre. The pointing work for rat-trap is time consuming and hence, labour-intensive. The two parallel leaves of 75 mm thick brick leaving a gap of 75 mm in between makes it rain waterproof. In conventional solid brick walls the external surface is plastered and painted to make it water proof. Coursed rubble stone wall is also pointed with 1:3 cement-sand mortar. Generally, the external surface of a cement stabilised mud block wall is rendered with 15 mm thick mud plaster with 8% cement stabilisation. Since the natural colour of stabilised mud plaster was acceptable to the villagers of Ranga Reddy district, it was not painted. The polished surface of interlocking cement stabilised mud block wall with 10% stabilisation was less water-absorbing and hence, a water repellent paint was applied on the external surface. In Andhra Pradesh Primary Education Project, polymer and cement mixed with water was used as a paint, which acted as a protective coat. When the interlocking cement stabilised mud block walls were inspected in January, 2000, minor surface flaking was observed that was glued back by applying the polymer-cement paint.

The internal surface treatment for the walls was similar, i.e., plastering and lime washing in general, except in cement stabilised mud block and interlocking cement stabilised mud block wall. Cement stabilised mud block wall, like its exterior treatment, is assumed to have mud plaster since cement plaster is not compatible with it. Interlocking cement stabilised mud block had a smooth surface, which did not require plastering and hence, only lime wash was applied directly on it. Many schools did not have access to electricity, therefore, to ensure adequate illumination level of the classrooms, large windows were provided and the interior surfaces of the walls were painted white. The following specifications have been adopted for the interior and exterior surface treatment of the walling systems.

- <u>Cement plastering</u>: It is applied on both interior and exterior of solid brick wall. For rat-trap wall, stone concrete block and coursed rubble stone masonry, this is applicable for the interior surface only. It is a two-coat plaster of 12 mm thickness finished with a sponge. The first coat is 8 mm thick in 1:5 cement-sand mortar and the second coat is 4 mm thick in 1:3 cement-sand mortar. It is water cured for seven days.

- **Mud plastering:** It is applied on cement stabilised mud block masonry wall both on interior and exterior. It is a two-coat plaster of 15 mm thickness, finished with a sponge. Mud plaster is mixed with 1:4:8 cement-screened sand-screened mud and with 0.7 water cement ratio. It is water cured for five days.

- **Flush pointing** It is applied on rat-trap, stone concrete block and coursed rubble stone masonry on the exterior. With a 10 mm wide purpose-made trowel, 1:3 cement-sand mortar is applied on the horizontal and vertical joints with adequate consolidation and polishing to create a flush pointed surface. It is water cured for at least seven days.

- **Lime washing:** It is applied on both interior and exterior of solid brick wall. This is applicable for the interior of rat-trap, cement stabilised mud block, interlocking cement stabilised mud block, stone concrete block and coursed rubble stone masonry wall. Pulverised Calcium Oxide, premixed with glue and blue colour are available in bags weighing 50 kilograms. The powder is mixed with water and applied three coats on the wall surface.

- **Polymer-cement paint:** It is applied on the exterior of interlocking cement stabilised mud block wall. Liquid latex and cement are mixed in 2:1 ratio by weight. The mix is applied on the wall surface thoroughly with a paint brush. Two to three hours after the first coat, the second coat is applied. It is water cured for three days.

Table 9.1 shows the detail of finishing items adopted for the walling systems under consideration. Table 9.2 and Table 9.3 show the socio-economic and environmental impacts of the basic structures and finished walling systems.

Table 9.1 External and internal finishes of the six walling systems.

Surface treatments	External		Internal	
Walling Systems	**Plastering or pointing**	**Decorative or protective paint**	**Plastering**	**Painting-three coats**
Solid brick wall	Cement plaster	Lime wash	Cement plaster	Lime wash
Rat-trap	Flush pointing	NA	Cement plaster	Lime wash
Cement stabilised mud block 5%	Mud Plaster	NA	Mud Plaster	Lime wash
Interlocking cement stabilised mud block 10%	NA	Polymer-cement	NA	Lime wash
Stone concrete block	Flush pointing	NA	Cement plaster	Lime wash
Coursed rubble stone	Flush pointing	NA	Cement plaster	Lime wash

Source: Author

Table 9.2 Socio-economic and environmental impacts of the six walling systems owing to the construction of the **basic structure** only. All the values are per square metre of the elevation area of the walls. (Rs.80 = £1)

	Socio-economic impact					Environmental impact			
Walling systems	Unit cost	Retained	Skilled	Semi skilled	Un skilled	Non renewable	Re-newable	Waste	CO_2
	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	MJ/ sq.m.	MJ/ sq.m.	MJ/ sq.m.	Kg./ sq.m.
Solid brick wall	228.70	134.23	11.77	12.40	40.23	74.38	16.01	553.19	76.57
Rat-trap	206.79	110.11	13.86	12.65	44.90	42.19	16.01	460.99	59.33
Cement Stabilised Mud Block 5%	214.49	55.05	17.27	0.00	57.77	134.15	16.01	0.01	31.07
Interlocking cement stabilised mud block 10%	178.95	40.66	3.15	5.66	36.96	167.43	10.44	0.01	39.55
Stone Concrete Block	210.87	47.63	13.61	0.00	67.38	188.81	13.23	0.04	34.20
Coursed Rubble Stone	316.37	104.53	20.38	0.00	97.41	151.34	26.45	0.01	32.84

Source: Adopted from Appendix V, Table V.1

Table 9.3 Socio-economic and environmental impacts of the six walling systems owing to the **internal and exterior finishes** only. All the values are per square metre of the elevation area of the walls. (Rs.80 = £1)

	Socio-economic Impacts					Environmental Impacts			
Walling systems	Unit cost	Retained	Skilled	Semi-skilled	Un skilled	Non renewable	Ren-newable	Waste	CO_2
	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	MJ/ sq.m.	MJ/ sq.m.	MJ/ sq.m.	Kg./ sq.m.
Solid brick wall	115.04	13.40	11.58	20.79	41.32	49.70	64.05	0.00	11.51
Rat-trap	86.74	10.01	9.22	16.56	29.97	37.83	48.04	0.00	8.78
Cement stabilised mud block 5%	78.74	10.05	10.30	18.48	30.53	17.00	48.04	0.00	3.89
Interlocking cement stabilised mud block 10%	62.20	7.03	4.58	2.31	9.39	26.74	16.01	0.00	0.77
Stone Concrete Block	86.74	10.01	9.22	16.56	29.97	37.83	48.04	0.00	8.78
Coursed Rubble Stone	86.74	10.01	9.22	16.56	29.97	37.83	48.04	0.00	8.78

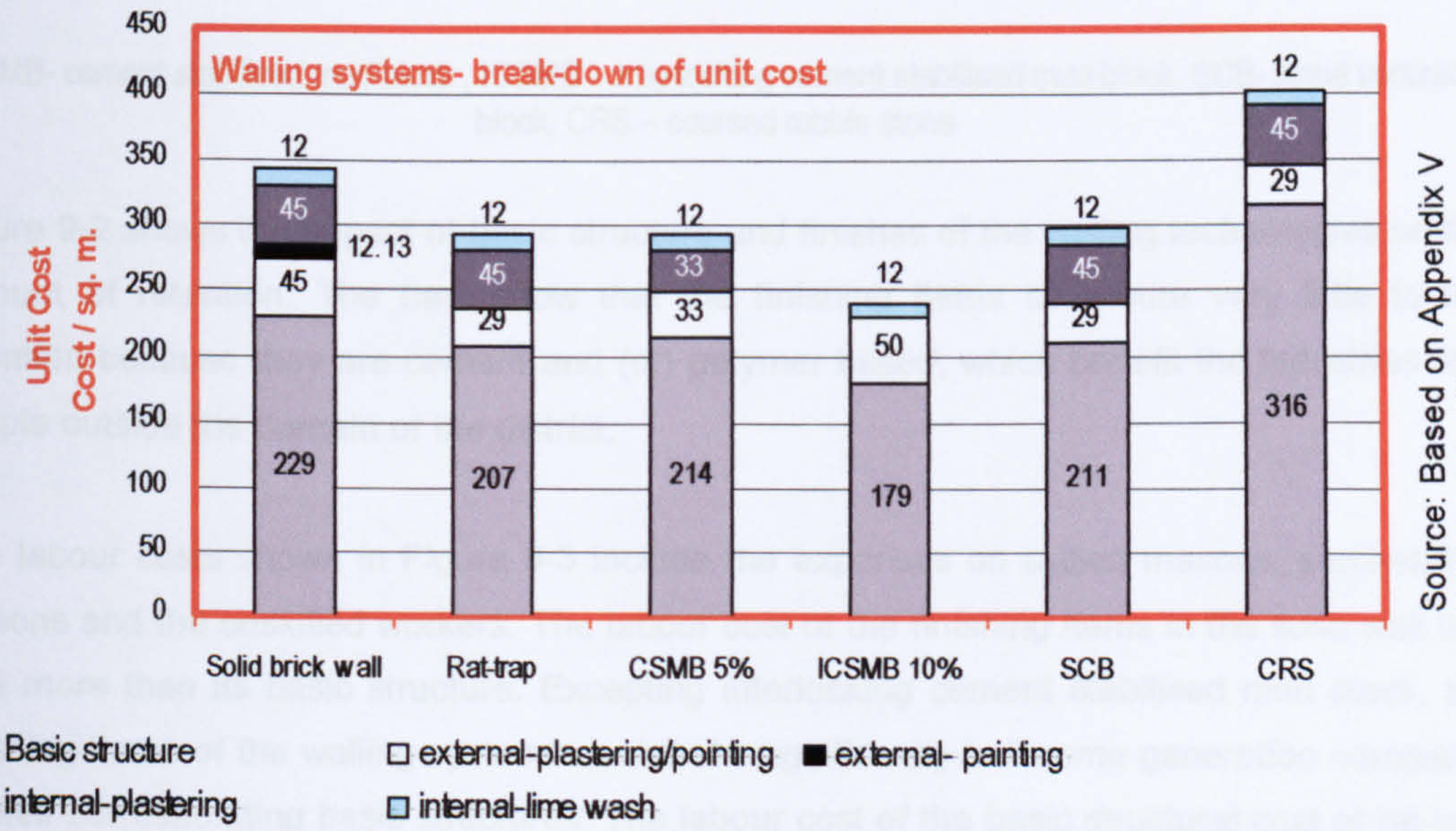
Source: By adding elements of the matrices in Appendix V, Table V.2 to V.5

9.2.3 Examining the Importance of Wall Finishes for Impact Assessment.

It is important to note that none of the books and articles mentioned in the "References" provide a database in Indian context on different walling systems as complete building components, i.e., including the finishing costs. The focus appears to be mostly on the basic structure. One of the biggest organizations in India, promoting the use of cost effective construction technologies, is the Building Materials and Technology Promotion Council, under the Ministry of Urban Affairs & Employment, Government of India. It has brought out many publications in this regard, e.g., "Housing and Key Building Materials in India" (BMTPC & STEM, 2000), etc. However, none of them ever addressed this aspect including their recent comprehensive document on building materials, 50 years after independence (Gupta, 1998). Therefore, there is a need for examining this issue to understand the implications of different finishing items applied on the basic structure.

The Table 9.2 and Table 9.3 have been presented to make a comparison between the impacts of the basic structure and the finished walling system. The unit cost columns of these two tables show that the impact of finishing items of the walls varies considerably. Based on the quantitative data presented in the two tables, the following figures will show the impacts of the basic structure and the finishing items of the walling systems on unit cost, retention, labour cost, embodied energy and CO_2 emission.

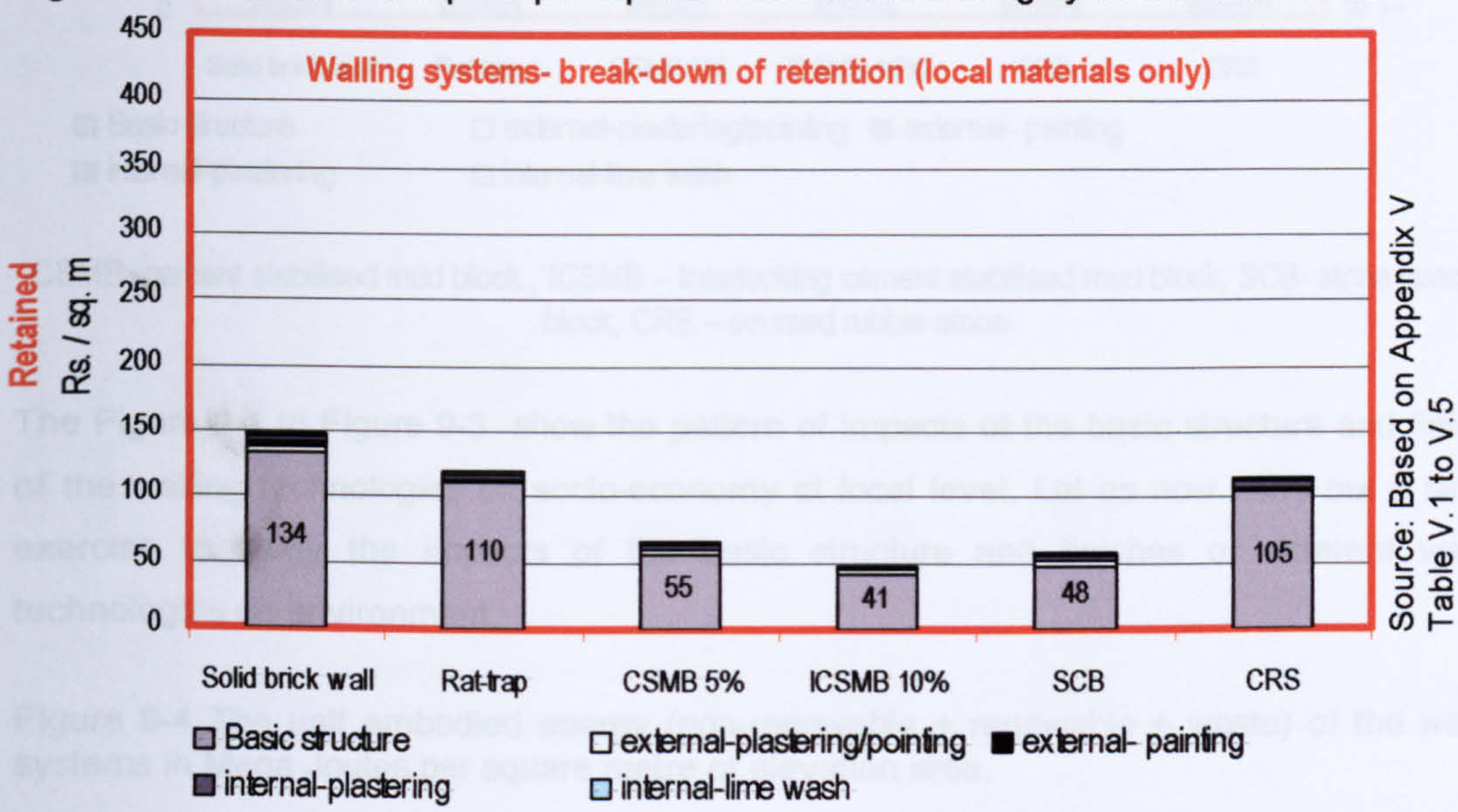
Figure 9-1 : The unit cost of the walling systems in rupees per square metre of the elevation area. Rs80 = £1.



CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 9-1 shows that the finishing costs of the walling systems are significant. Each bar shows the internal distribution of the expenses on the basic structure, external finishes and internal finishes of a particular walling system. The total finishing cost varies between Rs.62 (£0.78) per square metre (interlocking cement stabilised mud block) and Rs.114.13 (£1.43) per square metre (solid brick), which is 1.84 times the former. Therefore, there is a wide variation in finishing costs of the walling systems. It is important to note that the percentage of finishing costs may be considerable, e.g., the finishing cost of rat-trap wall is about 42% of its basic structural cost, whereas it is 35% in case of interlocking cement stabilised mud block wall, which does not require internal plastering because of its smooth surface.

Figure 9-2: Retention in rupees per square metre of the walling systems. Rs80 = £1.

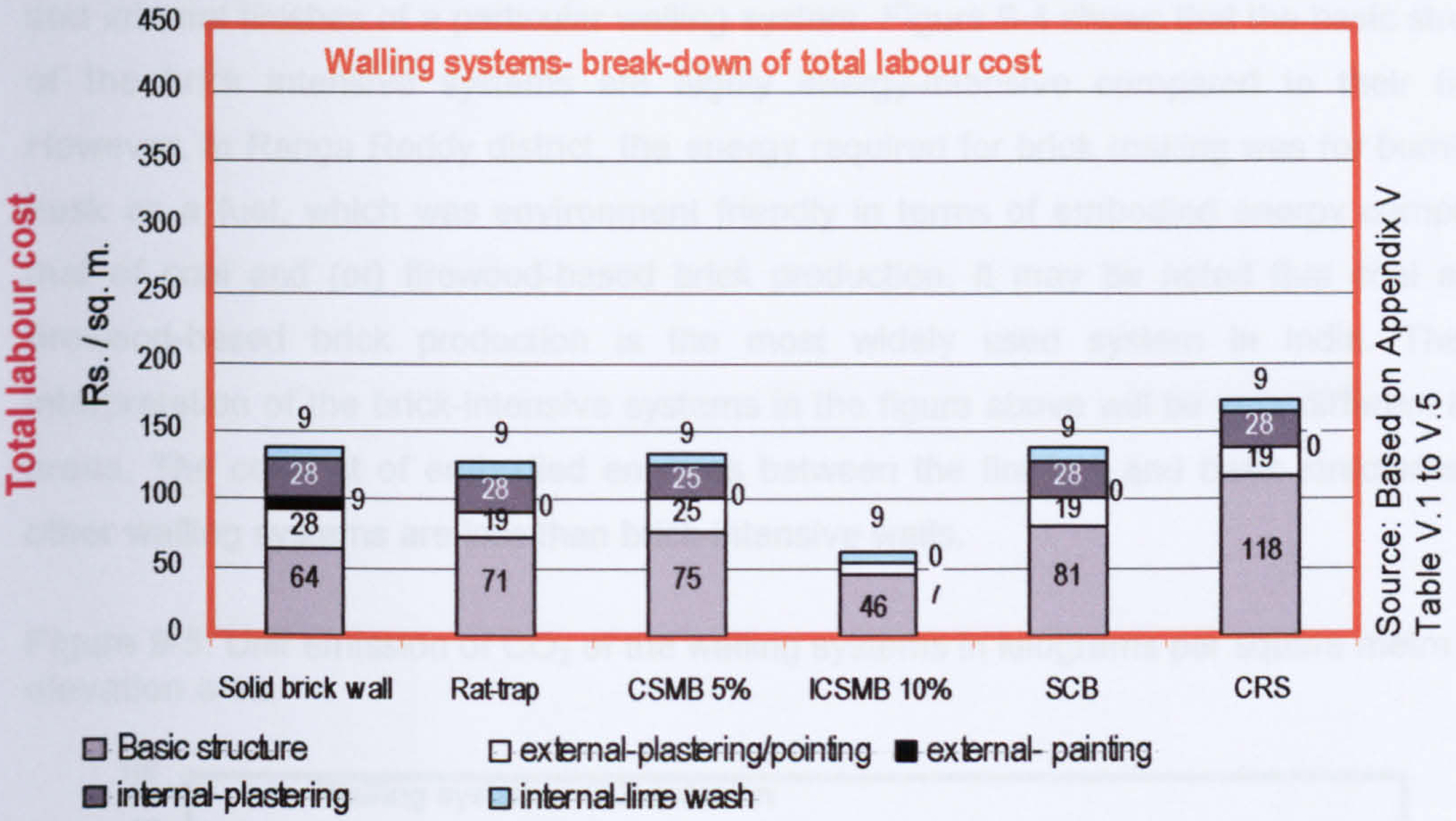


CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 9-2 shows the impact of basic structure and finishes of the walling technologies on the amount of retention. The bars show that the finishing items contribute very little to the retention because they are cement and (or) polymer based, which benefit the industries and people outside the domain of the district.

The labour costs shown in Figure 9-3 include the expenses on skilled masons, semi-skilled masons and the unskilled workers. The labour cost of the finishing items in the solid wall is a little more than its basic structure. Excepting interlocking cement stabilised mud block, the finishing items of the walling systems contribute significantly in income generation compared to their corresponding basic structures. The labour cost of the basic structural cost of rat-trap wall is Rs.71 (£0.89) per square metre and Rs.56 (£0.7) per square metre for the finishes. The main reason for finishing costs being high is the labour-intensive pointing on the external wall surface of rat-trap wall. Cement stabilised mud block masonry also has a similar pattern.

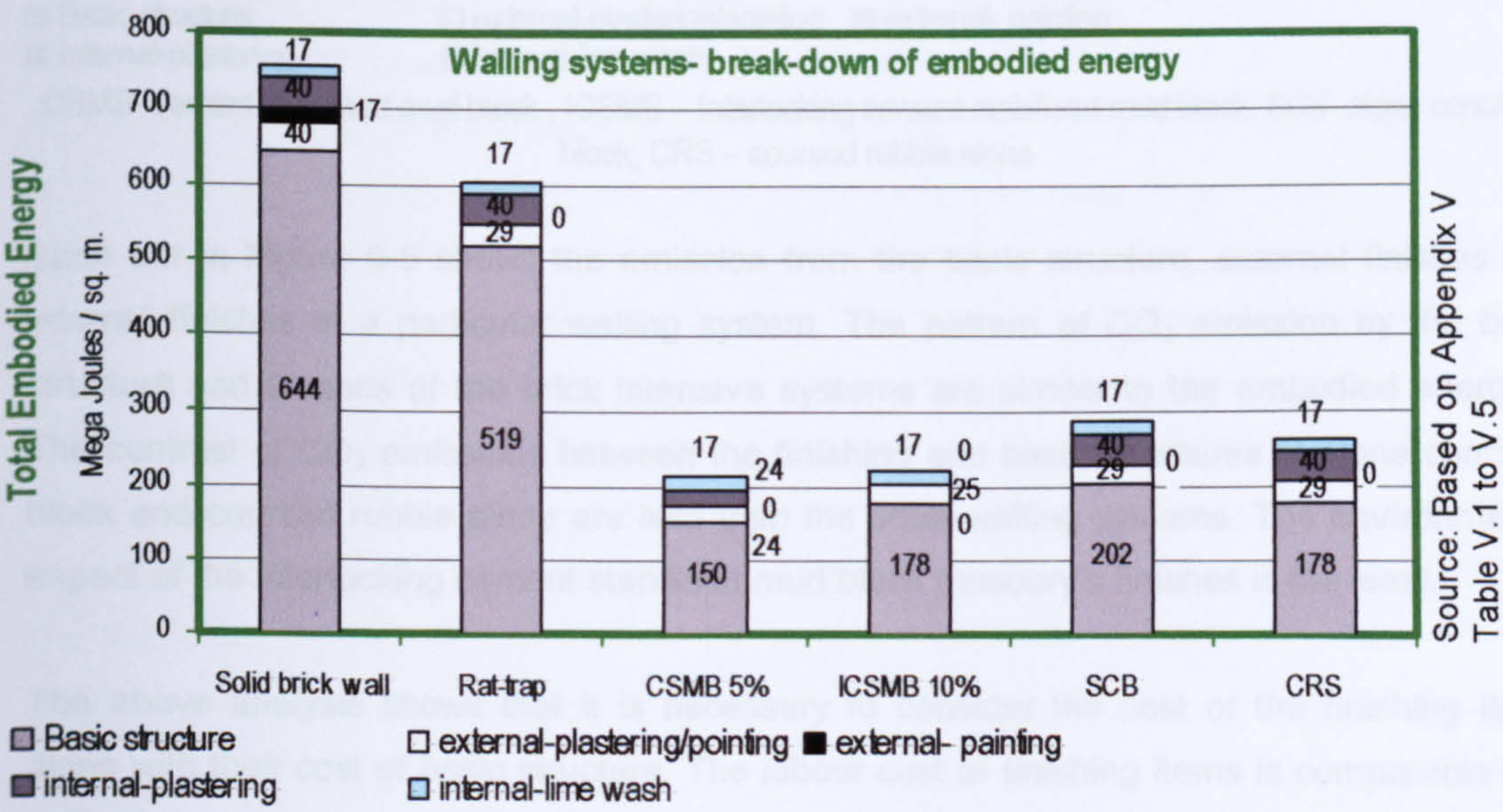
Figure 9-3 Unit labour cost in rupees per square metre of the walling systems. Rs80 = £1.



CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

The Figure 9-1 to Figure 9-3 show the pattern of impacts of the basic structure and finishes of the walling technologies on socio-economy at local level. Let us now carry out a similar exercise to study the impacts of the basic structure and finishes of different walling technologies on environment.

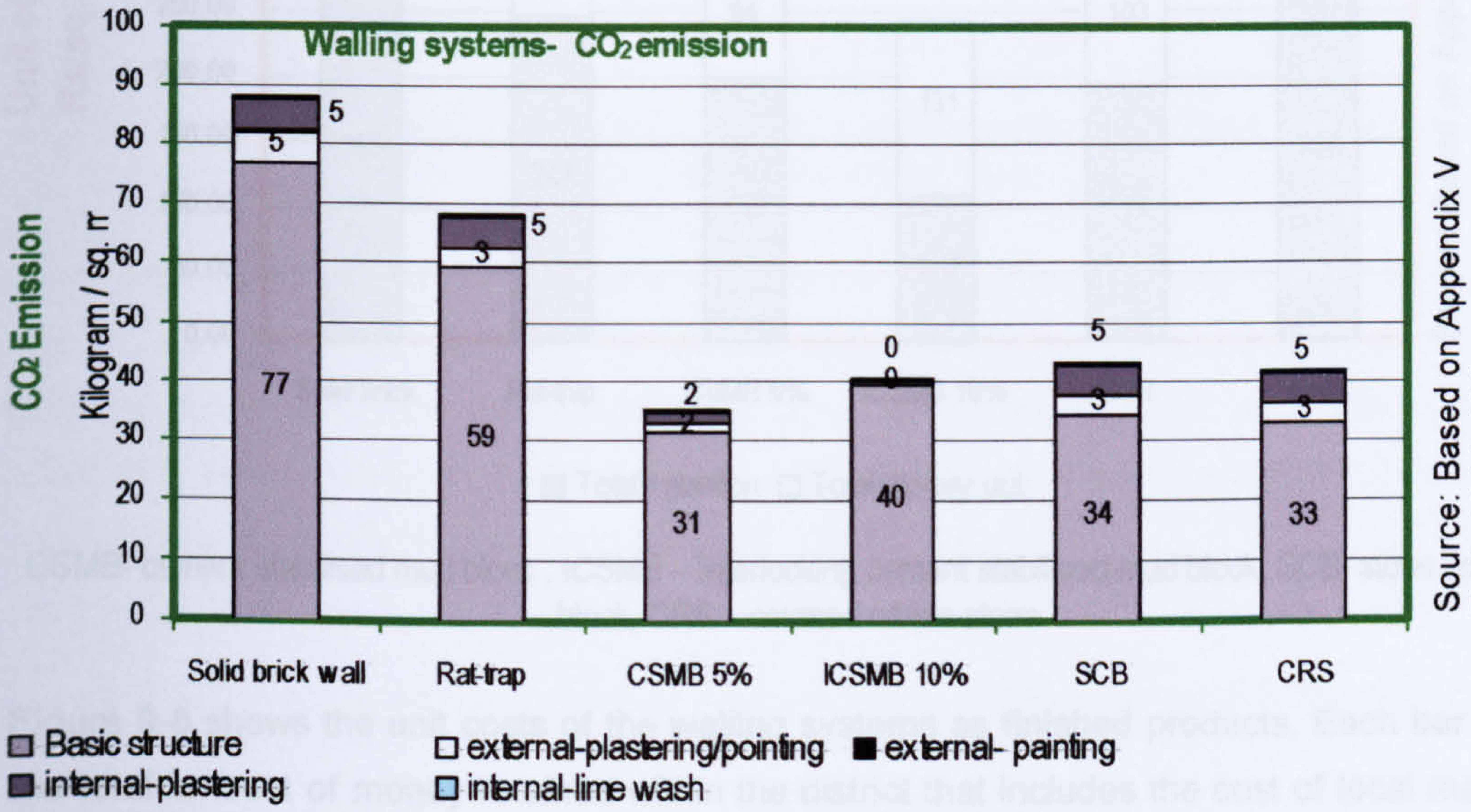
Figure 9-4 The unit embodied energy (non-renewable + renewable + waste) of the walling systems in Mega Joules per square metre of elevation area.



CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Each bar in Figure 9-4 shows the embodied energy of the basic structure, external finishes and internal finishes of a particular walling system. Figure 9-4 shows that the basic structures of the brick intensive systems are highly energy-intensive compared to their finishes. However, in Ranga Reddy district, the energy required for brick making was for burning rice husk as a fuel, which was environment friendly in terms of embodied energy compared to that of coal and (or) firewood-based brick production. It may be noted that coal and (or) firewood-based brick production is the most widely used system in India. Therefore, interpretation of the brick-intensive systems in the figure above will be very different in other areas. The contrast of embodied energies between the finishes and basic structures of the other walling systems are less than brick-intensive walls.

Figure 9-5: Unit emission of CO_2 of the walling systems in kilograms per square metre of elevation area.



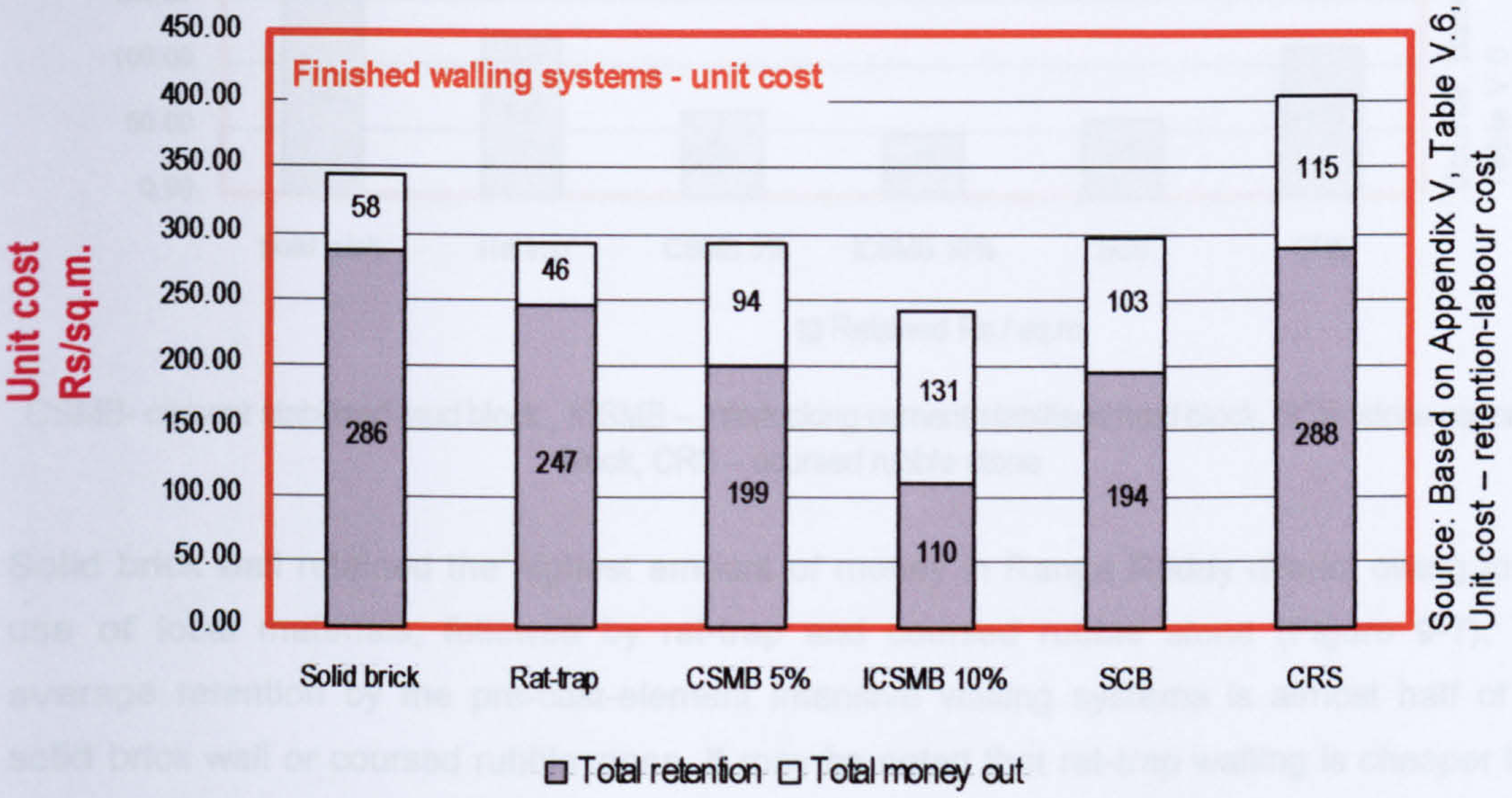
CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Each bar in Figure 9-5 shows the emission from the basic structure, external finishes and internal finishes of a particular walling system. The pattern of CO_2 emission by the basic structure and finishes of the brick intensive systems are similar to the embodied energies. The contrast of CO_2 emissions between the finishing and basic structures of stone concrete block and coursed rubble stone are less than the other walling systems. The environmental impact of the interlocking cement stabilised mud block masonry's finishes is the least.

The above analysis shows that it is necessary to consider the cost of the finishing items along with their cost of basic structure. The labour cost of finishing items is comparable with that of the basic structure and hence, very important for employment generation. The contribution of finishing items is insignificant in retention owing to the use of cement based materials. The Embodied energies of the finishes are high in coursed rubble stone and stone concrete block compared to that of their basic structure. The pattern of CO_2 emission of the finishes is similar to that of the embodied energies. Therefore, from this point onwards, walling technologies will always be inclusive of the finishes.

9.2.4 Analysis of the Database of Walling Systems as Finished Products

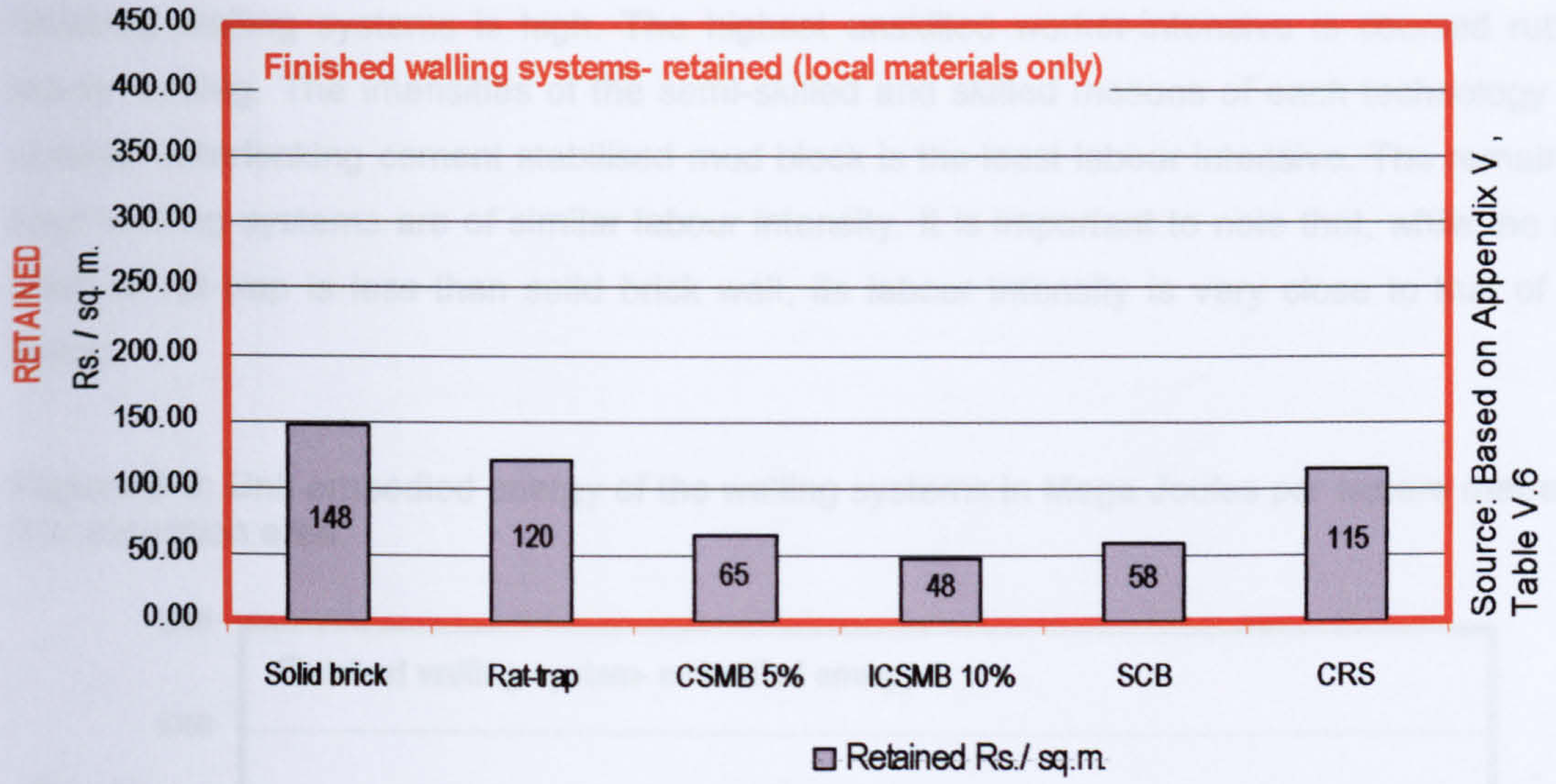
Figure 9-6: The unit costs of the six walling systems including the internal distribution of the amount of money retained in and going out of the district. Rs80 = £1.



CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 9-6 shows the unit costs of the walling systems as finished products. Each bar shows the total amount of money retained within the district that includes the cost of local materials and labour expenses. The portion of each bars showing money out of the district includes the cost of non-local materials and cost of coal, diesel and electricity for the production of local materials. Interlocking cement stabilised mud block is the least expensive walling systems and costs about Rs.241 (£3) per square metre, which is 40% cheaper than coursed rubble stone wall that costs Rs.403 (£5) per square metre. However, interlocking cement stabilised mud block is the least supportive to income generation, since more than 50% of the total walling cost goes out of the district because it is cement-intensive. While the unit cost of rat-trap, cement stabilised mud block and stone concrete block are very similar, rat-trap retains the maximum amount of money within the district and, hence, generates the most income out of these three walling systems.

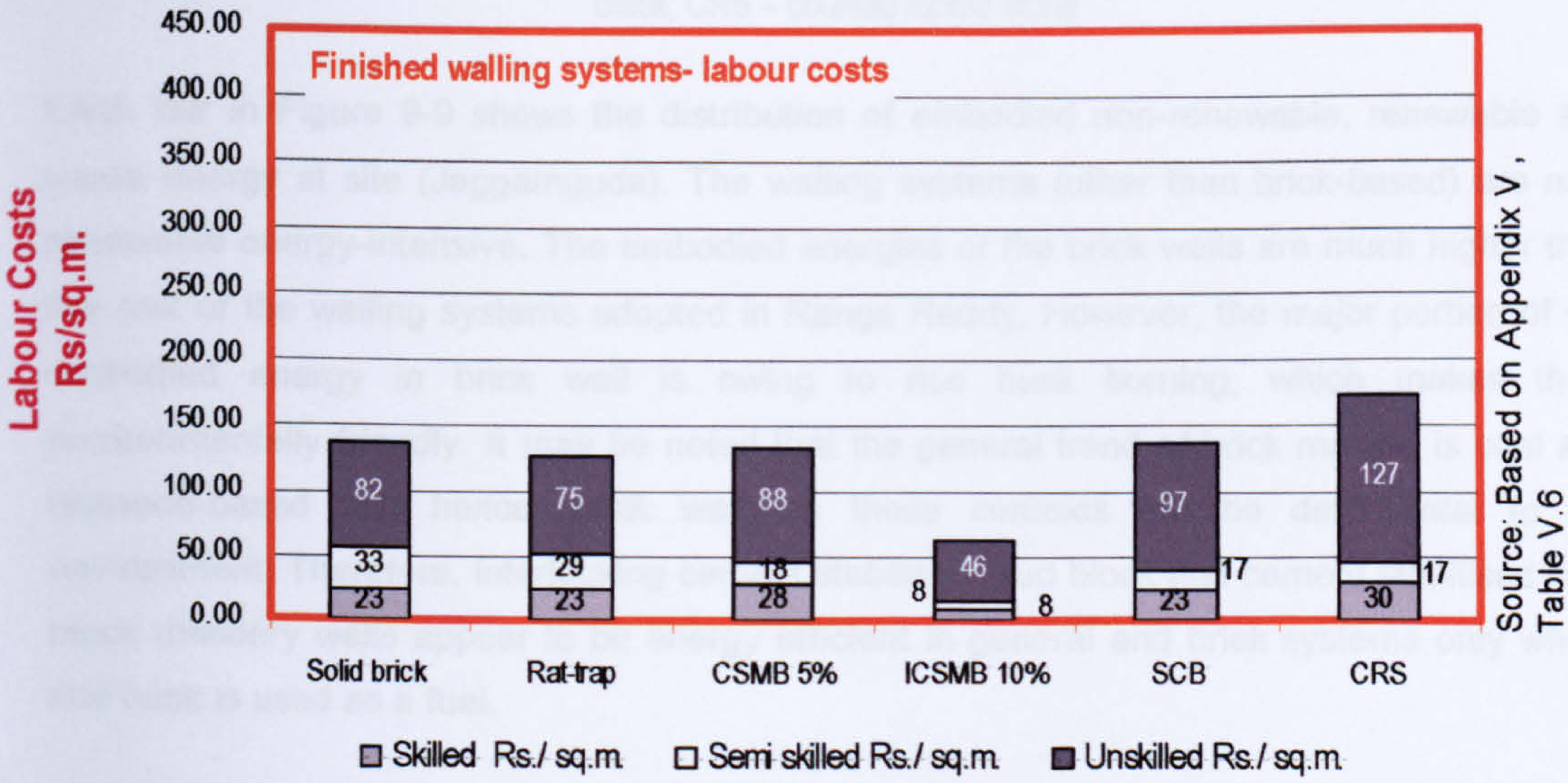
Figure 9-7: The amount of money that goes to the local building material suppliers in the construction of different walling systems. Rs80 = £1



CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Solid brick wall retained the highest amount of money in Ranga Reddy district owing to the use of local materials, followed by rat-trap and coursed rubble stone (Figure 9-7). The average retention by the pre-cast-element intensive walling systems is almost half of the solid brick wall or coursed rubble stone. It may be noted that rat-trap walling is cheaper than solid brick and coursed rubble stone masonry (Figure 9-6).

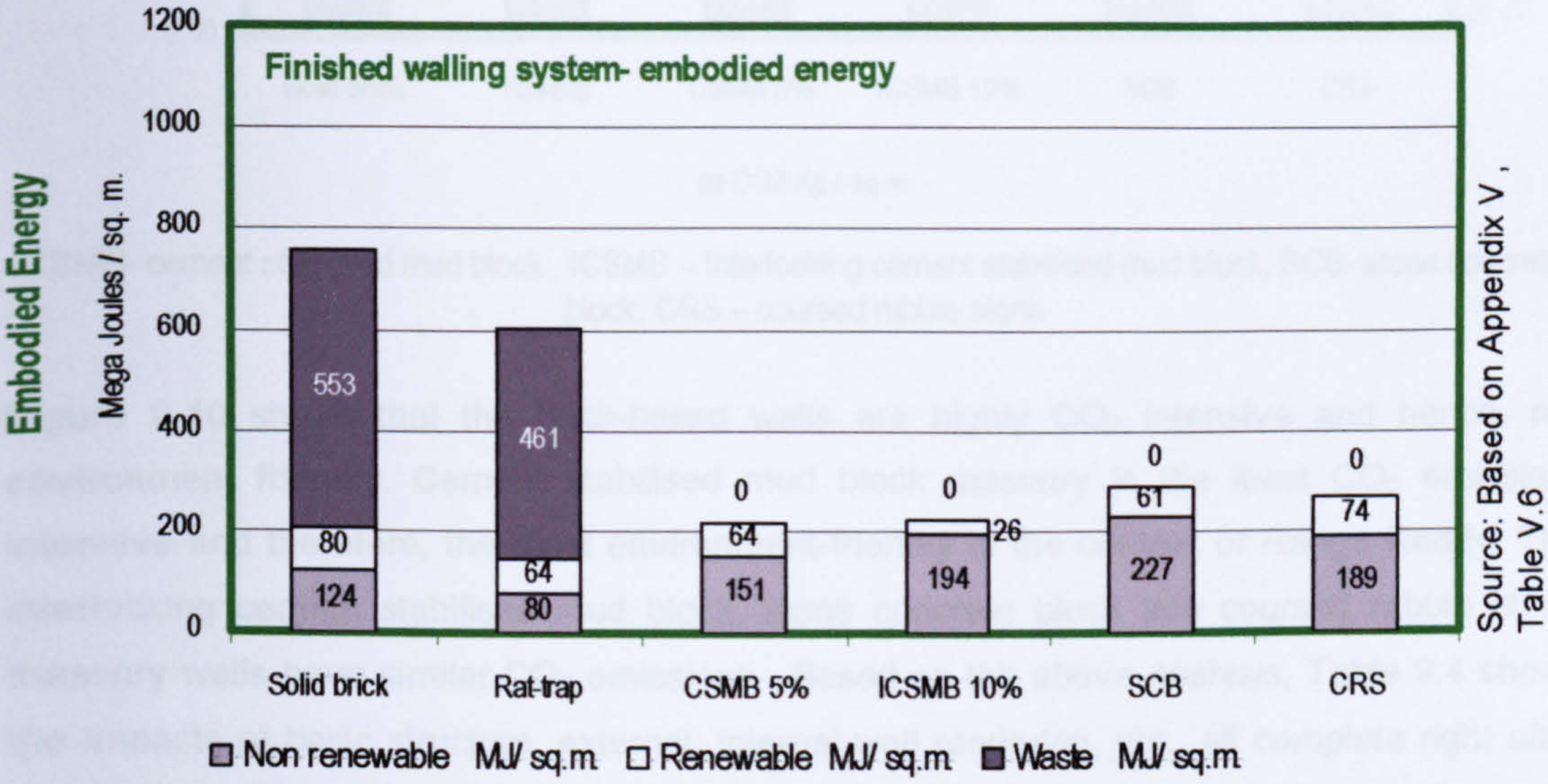
Figure 9-8 The labour intensity of the finished walling systems adopted in Ranga Reddy. Rs80 = £1



CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Each bar in Figure 9-8 shows the expenses on skilled masons, semi-skilled masons and unskilled workers. Figure 9-8 shows that the unskilled construction workers' intensity of finished walling systems is high. The highest unskilled worker-intensive is coursed rubble stone walling. The intensities of the semi-skilled and skilled masons of each technology are similar. Interlocking cement stabilised mud block is the least labour intensive. The remaining four walling systems are of similar labour intensity. It is important to note that, while the unit cost of rat-trap is less than solid brick wall, its labour intensity is very close to that of the latter.

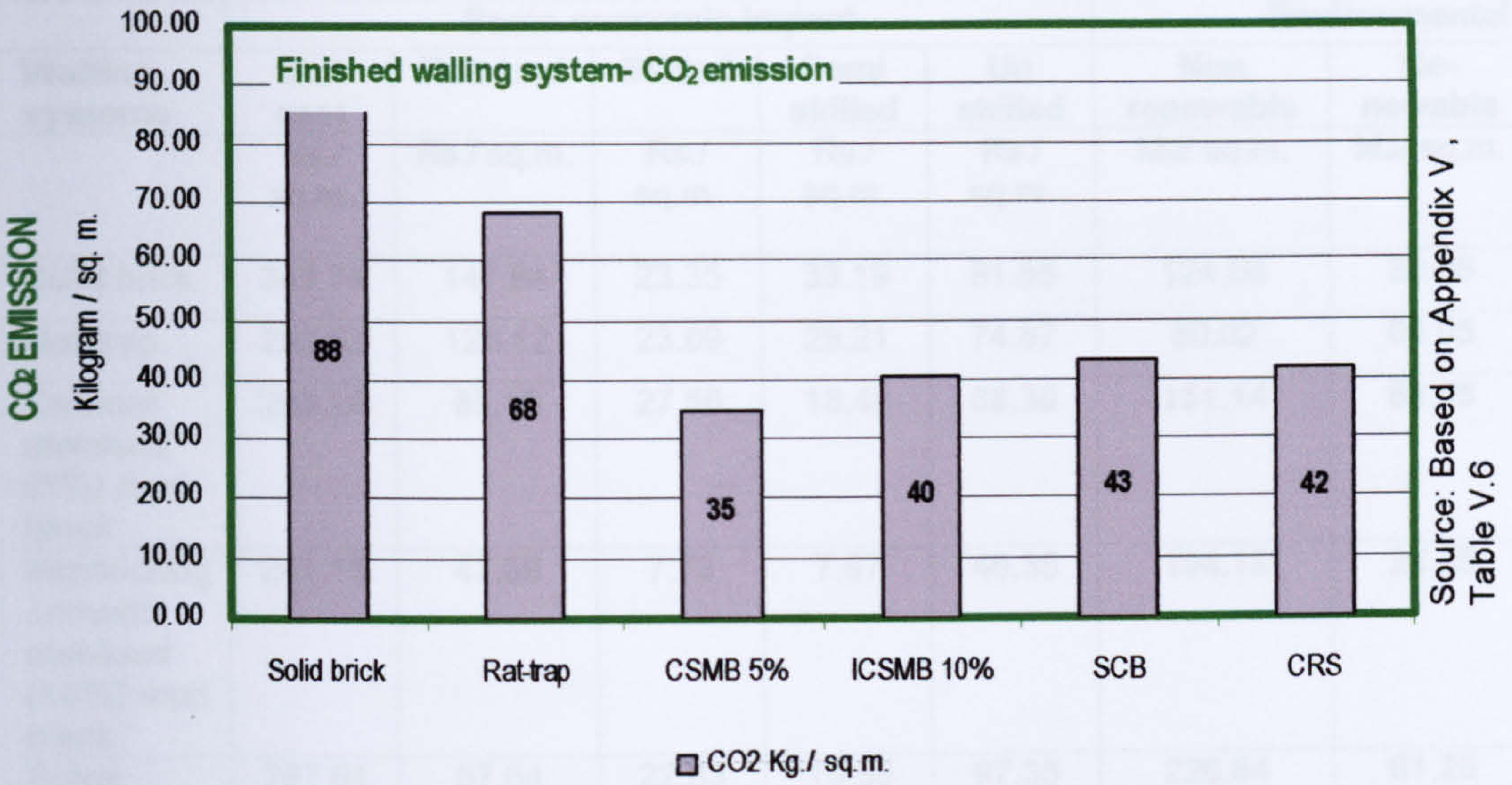
Figure 9-9: Unit embodied energy of the walling systems in Mega Joules per square metre of the elevation area.



CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Each bar in Figure 9-9 shows the distribution of embodied non-renewable, renewable and waste energy at site (Jaggamguda). The walling systems (other than brick-based) are non-renewable energy-intensive. The embodied energies of the brick walls are much higher than the rest of the walling systems adopted in Ranga Reddy. However, the major portion of the embodied energy in brick wall is owing to rice husk burning, which makes them environmentally friendly. It may be noted that the general trend of brick making is coal and firewood-based and hence, brick walls in those contexts will be detrimental to the environment. Therefore, interlocking cement stabilised mud block and cement stabilised mud block masonry walls appear to be energy efficient in general and brick systems only where rice husk is used as a fuel.

Figure 9-10 CO_2 emission in kilogram per square metre (of elevation area) owing to the use of different walling systems adopted in Ranga Reddy district.



CSMB- cement stabilised mud block , ICSMB – Interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 9-10 shows that the brick-based walls are highly CO_2 intensive and hence, not environment friendly. Cement stabilised mud block masonry is the least CO_2 emission-intensive and therefore, the most environment-friendly in the context of Ranga Reddy. The interlocking cement stabilised mud block, stone concrete block and coursed rubble stone masonry walls have similar CO_2 emissions. Based on the above analysis, Table 9.4 shows the impacts of basic structure, external, internal wall rendering, etc., all complete right after construction. This data will be adopted for impact assessment. All values are in square metre of elevation area of the walling systems.

Table 9.4 Socio-economic and environmental impacts of the **six walling systems** (basic structure + finishes). Impacts are per square metre of wall elevation. (Rs.80 = £1)

	Socio-economic impact					**Environmental impact**			
Walling systems	**Unit cost**	**Retained**	**Skilled**	**Semi skilled**	**Un skilled**	**Non renewable**	**Re-newable**	**Waste**	**CO_2**
	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	MJ/ sq.m.	MJ/ sq.m.	MJ/ sq.m.	Kg./ sq.m.
Solid brick	343.74	147.64	23.35	33.19	81.55	124.08	80.06	553.19	88.08
Rat-trap	293.52	120.12	23.09	29.21	74.87	80.02	64.05	460.99	68.11
Cement stabilsed (5%) mud block	293.24	65.10	27.56	18.48	88.30	151.14	64.05	0.01	34.96
Interlocking cement stabilsed (10%) mud block	241.15	47.69	7.73	7.97	46.35	194.18	26.45	0.01	40.31
Stone concrete block	297.61	57.64	22.83	16.56	97.35	226.64	61.26	0.04	42.98
Coursed rubble stone	403.11	114.54	29.60	16.56	127.38	189.17	74.49	0.01	41.63

Source: Adopted from Table V.6, Appendix V

9.3 ROOFING SYSTEMS

The roofing systems have been divided into three groups. The group-1 consists of cement and steel-intensive pre-cast roofing elements. This group has the minimum in-situ process. The group-2 roofs need under-structure to support the discrete elements such as micro concrete tiles, stone slab and brick arches. The last group is mostly cast-in-situ and are based on level-1 materials.

9.3.1 Roofing: Basic structure

The basic structural cost of a roof is the total amount of money spent on the materials, labour, equipment, etc., and it does not include finishing and waterproofing. For example, the basic cost of a reinforced cement concrete roof slab is the investment on stone chips, sand, cement, water, shuttering, mixing machine, and vibrator including curing. However, to make a roof complete, one needs to plaster and paint the ceiling and lay a waterproofing impervious coat on the roof top. Following is the description of the three groups of roofing.

ROOFING GROUP-1: (PRE-CAST-INTENSIVE)

- Reinforced cement concrete plank and joist
- Reinforced cement concrete channel
- Ferrocement channel

The detailed descriptions of the systems are in Appendix IV. The group-1 roofing systems are constructed by using pre-cast components from the local building centre and then transported to the site by 12.5 tons capacity diesel operated TATA truck. The in-situ work is small and is limited to the joint sealing and waterproofing. The first two systems need an impervious coat of 50 mm, 1:3 cement sand mortar with 0.2 % waterproofing compound. All these roofs are flat and require a wall height of 3000 mm.

ROOFING GROUP -2 (PART PRE-CAST)

- Micro concrete tiles roofing with steel and timber under-structure.
- Stone roofing on pre-cast reinforced cement concrete joists
- Jack-arch on pre-cast reinforced cement concrete joists

This group requires under-structure. Micro concrete tiles are placed on timber purlins, which are supported on steel rafters. The entire under-structure could be made of steel, timber, reinforced cement concrete, ferrocement or bamboo. The stone and jack-arch roofing are supported on pre-cast reinforced cement concrete joists (Appendix-IV).

The following roofing systems are constructed by using pre-cast components from the local building centre, which are transported to the site by 12.5 tons capacity diesel operated TATA truck. The in-situ work involved in the following systems is more than the group-1, however, less than group-3. For example, an under-structure of steel or timber or a combination of steel and timber is required to support the micro concrete tiles. In both stone and jack-arch roofing, pre-cast reinforced cement concrete joists are required as support to the stone plates and brick arches. This is followed by the in-situ waterproofing on roof top and painting of the ceiling. Stone and jack-arch roofing are flat and require a 3000 mm wall height. Micro concrete tiles, used as sloped roof, required an average wall height of 2700 mm.

ROOFING GROUP -3 (IN-SITU)

- Reinforced cement concrete slab
- Hybrid slab
- Reinforced cement concrete filler slab
- Brick corbel arch
- Brick pyramid

Construction of the above roofing systems involves mostly in-situ works. Reinforced cement concrete roof is the most cement and steel-intensive system followed by the hybrid and filler slab. All three require shuttering, on which the reinforcing rods are placed and then concrete casting takes place. In hybrid slab, the brick panels are constructed first and then concreting takes place. In case of filler slab the filler materials, such as a pair of clay tiles, are placed between reinforcing rods just before concrete casting so that movements of the construction workers do not break the tiles.

Corbelled arch and pyramid roofs are brick-intensive and do not require any form of shuttering or scaffolding. It may be noted that, if the masons are not used to the construction of this type of structure, there may be a need for underside finishing for which scaffolding is required. These two types of roofing systems require waterproofing plaster on top.

Reinforced cement concrete slab and hybrid slab are flat and hence, require a wall height of 3000 mm. The filler slab with a slope of about 25 degrees requires 2400 mm. Brick corbel arch requires 1800 mm and brick pyramid requires 2100 mm of wall heights.

9.3.2 Roofing: Finishes

As mentioned before, literature on cost effective technologies, in general, provide information only on the basic structural costs of walls and roofs. The last section on the six walling systems has demonstrated that some of the wall finishes have significant impacts on the socio-economy and environment. This section will examine whether the roof treatments and soffit finishes also have as significant impact on socio-economy and environment as the walls. It may be noted that each roofing option has one or two compatible waterproofing technologies, out of which the ones adopted in Andhra Pradesh Primary Education Project have been considered here. Although the ceiling finishes have a wide choice, only white wash has been considered for all the roofing systems since that is usually the cheapest of all the available options.

The following are the specifications of the roof-top treatment and ceiling finishes of different roofing systems.

- <u>Roof-top impervious coat</u>: It is a 20 mm thick cement sand plaster (1:3) with polymer-based waterproofing compound (0.2% of the weight of cement used). This type of impervious plaster is applied on reinforced cement concrete slab, jack-arch roof, hybrid slab, etc. The plaster is cured for at least seven days.

- **Brickbat coba:** Wire-cut bricks or brick tiles of strength not less than 75 kilogram per square centimetres are placed on freshly laid 25 mm thick 1:4 cement sand mortar with polymer based waterproofing compound (0.2% of the weight of cement used) on the rooftop. The bricks are placed with a gap of about 15 mm all-around, which is filled with the same mortar and tightly pointed with 1:3 cement sand mortar. The roof treatment is cured at least for seven days. This type of roof treatment is done for sand stone roofing.

- **Lime washing:** It is applied on the soffit of reinforced cement concrete slab, ribs of hybrid slab, etc. Pulverised Calcium Oxide, premixed with glue and blue colour are available in bags weighing 50 kilograms. The powder is mixed with water and applied three coats on the wall surface.

- **Polymer-cement paint:** It is applied on cracked masonry, ferrocement channel roof, etc. Liquid latex, cement and screened sand are mixed in 2:1:1 ratio by weight. The mix is applied on the roof surface thoroughly with a paint brush. Two to three hours after the first coat, the second coat is applied. The third coat is applied with liquid latex only. It is cured for three days.

Table 9.5 shows the detail of finishing items adopted for the roofing systems under consideration. Figure 9-6 and Figure 9-7 show the socio-economic and environmental impacts of the basic structures and finishing items of the roofing systems. All values are in square metre of plan area of the roofing systems.

Table 9.5 Waterproofing treatments and ceiling finishes of the roofing systems

Surface Treatments	Waterproofing treatments	Ceiling finishes
Roofing systems		
Reinforced cement concrete slab	Impervious coat	Three coats of lime wash
Reinforced cement plank and joist	Impervious coat	Three coats of lime wash
Reinforced cement channel	Impervious coat	Three coats of lime wash
Ferrocement channel	Polymer cement paint	Three coats of lime wash
Micro concrete tiles roofing	None	Oil bound paint on the under structure
Hybrid slab	Impervious coat	Three coats of lime wash only on ribs
Filler slab	Impervious coat	Three coats of lime wash
Stone roofing	Brickbat coba	Three coats of lime wash only on ribs
Jack-arch roofing	Impervious coat	Three coats of lime wash only on ribs
Brick corbel arch	Impervious coat	None
Brick pyramid	Impervious coat	None

Source: Author

Table 9.6: Socio-economic and environmental impacts of the eleven roofing systems owing to the construction of **basic structure** only (values are per square metre of plan area). (Rs.80 = £1)

	Socio-economic impact					Environmental impact			
Roofing systems	**Unit cost**	**Retained**	**Skilled**	**Semi skilled**	**Un skilled**	**Non renewable**	**Re-newable**	**Waste**	**CO_2**
	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	MJ/ sq.m.	MJ/ sq.m.	MJ/ sq.m.	Kg./ sq.m.
Reinforced cement concrete in-situ	411.38	121.35	12.94	1.69	33.97	471.19	119.17	2.08	74.86
Reinforced cement concrete plank and joist	348.61	62.88	23.84	9.01	42.33	454.19	20.65	0.38	69.36
Reinforced cement concrete channel	360.40	63.14	17.04	7.57	58.76	454.41	20.65	0.38	68.74
Ferrocement channel	350.84	39.93	13.18	11.53	67.23	408.93	0.00	0.01	61.10
Micro concrete tile roofing	249.94	75.01	38.92	0.09	25.98	230.89	9.77	0.62	32.61
Hybrid	412.24	147.67	20.01	18.50	42.63	381.41	133.28	178.41	81.28
Reinforced cement concrete filler	364.69	136.55	38.91	12.60	56.27	253.75	218.97	41.99	56.32
Stone on joist	378.32	61.00	26.06	6.06	55.04	425.21	13.86	0.26	60.85
Jack-arch on joists	361.78	117.75	21.93	10.78	49.00	336.36	20.65	323.56	85.16
Brick corbel arch	413.82	148.30	62.83	63.74	105.08	55.18	0.00	633.54	80.81
Brick pyramid	360.48	144.29	50.11	20.91	103.39	68.00	0.00	609.47	81.09

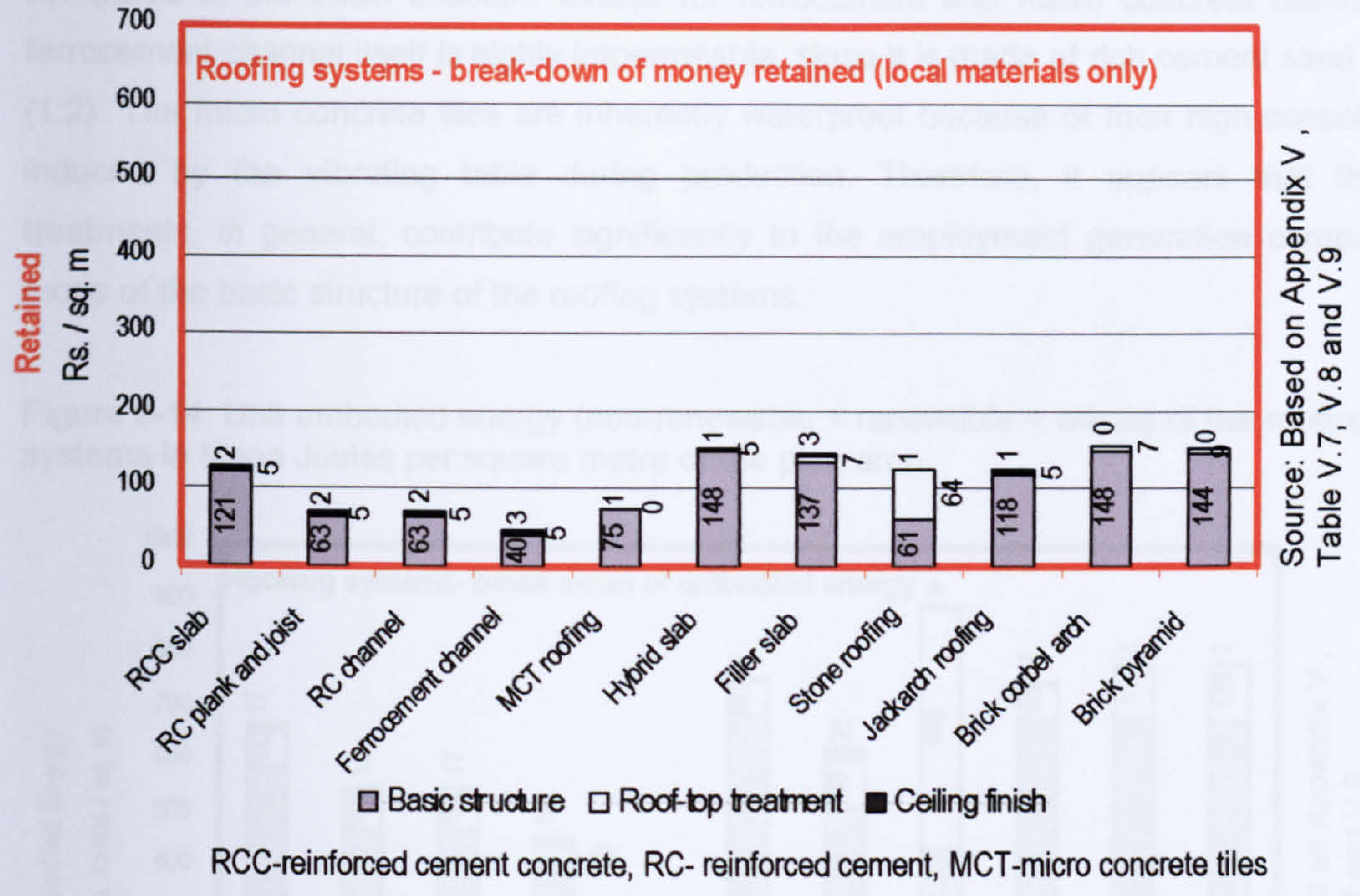
Source: Adopted from Appendix V, Table V.7

Table 9.7 Socio-economic and environmental impacts of the eleven roofing systems owing to the **waterproofing and ceiling finish** only (values are per square metre of the elevation). (Rs.80 = £1)

	Socio-economic impact					Environmental impact			
Roofing systems	**Unit cost**	**Retained**	**Skilled**	**Semi skilled**	**Un skilled**	**Non renewable**	**Re newable**	**Waste**	**CO_2**
	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	MJ/ sq.m.	MJ/ sq.m.	MJ/ sq.m.	Kg./ sq.m.
Reinforced cement concrete in-situ	73.30	7.083	6.006	10.780	19.665	60.861	16.012	0.003	12.50
Reinforced cement concrete plank and joist	73.30	7.083	6.006	10.780	19.665	60.861	16.012	0.003	12.50
Reinforced cement concrete channel	73.30	7.083	6.006	10.780	19.665	60.861	16.012	0.003	12.50
Ferrocement channel	70.92	7.976	5.198	2.541	10.516	30.685	17.613	0.000	0.865
Micro concrete tile roofing	16.26	0.946	3.956	0.000	4.590	8.987	0.000	0.000	1.221
Hybrid	65.91	5.694	5.221	9.371	16.201	60.049	6.245	0.003	12.26
Reinforced cement concrete filler	108.49	10.483	8.889	15.954	29.105	90.074	23.698	0.004	18.46
Stone on joist	226.09	65.324	10.478	1.155	25.311	256.513	8.006	192.29	71.20
Jack-arch on joists	71.90	6.152	5.680	10.195	17.543	65.988	6.245	0.003	13.47
Brick corbel arch	111.50	7.688	10.031	18.004	29.648	92.720	1.498	0.005	20.90
Brick pyramid	128.55	8.863	11.565	20.757	34.182	106.900	1.727	0.004	18.21

Source: By adding the elements of Appendix V Table V.8 and Table V.9

Figure 9-12: Retention of the roofing systems in rupees per square metre of the plan area. Rs80 = £1



The Figure 9-12 shows that the retention of the waterproofing treatments and ceiling finish, in general, are very low compared to that of the basic structures. The use of cement-intensive treatments was the main reason behind this. In Ranga Reddy, lime was brought from outside the district and hence, the ceiling treatment also did not retain a significant amount of money within the district. The only visible retention is in stone roofing, which could be attributed to the use of local bricks in the brickbat coba treatment.

Figure 9-13: Unit labour cost in rupees per square metre of the roofing systems. Rs80 = £1.

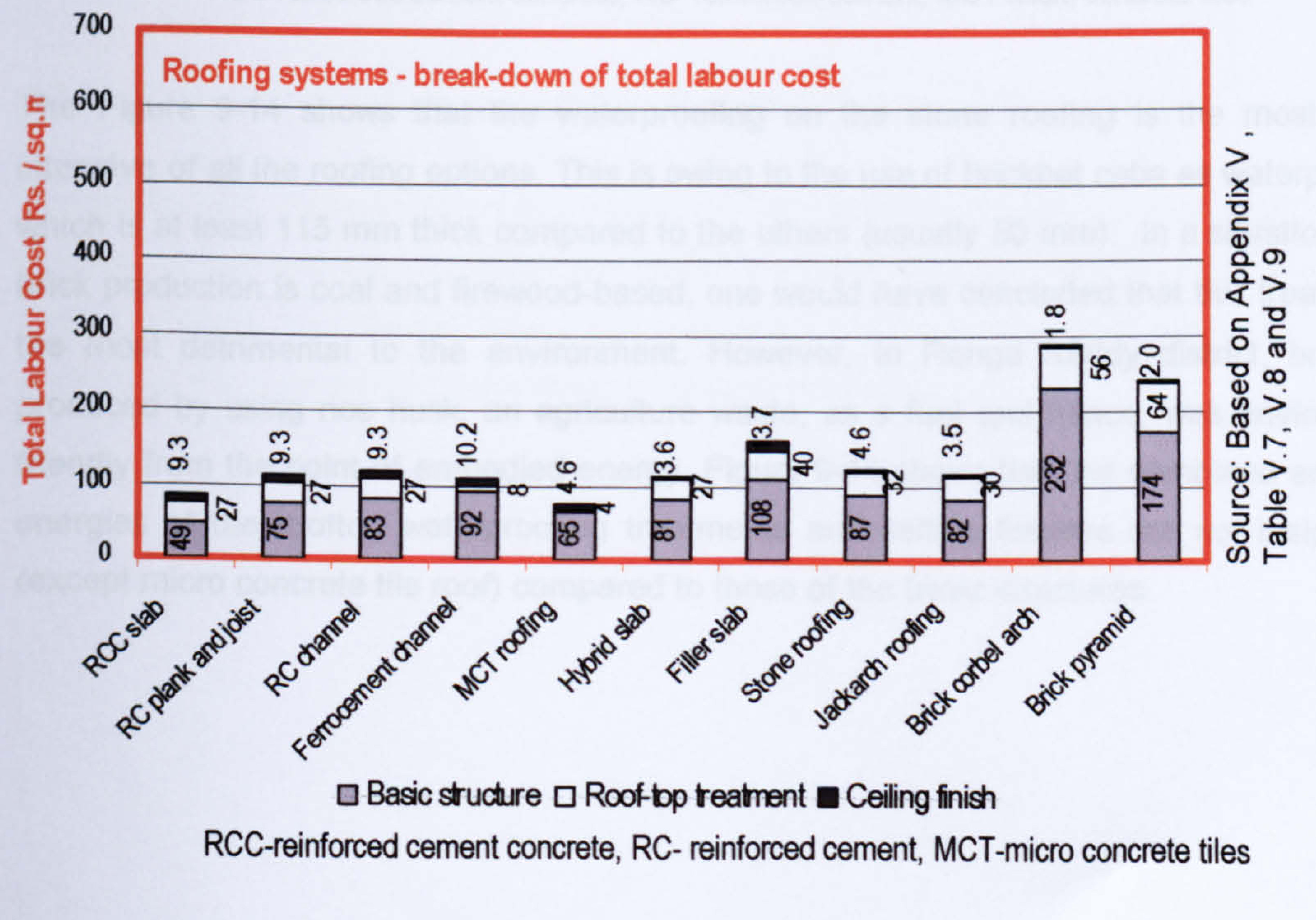
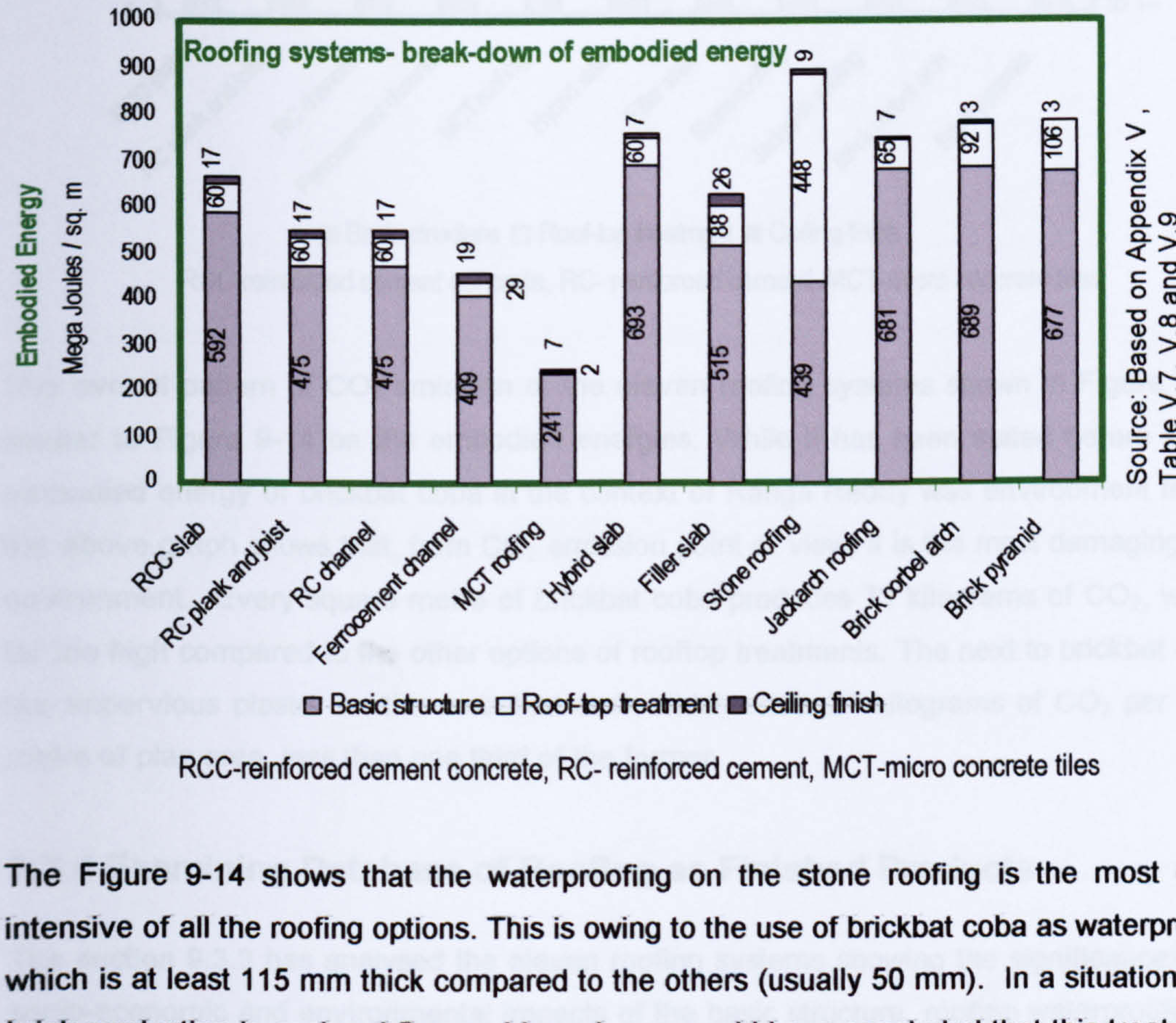


Figure 9-13 shows that the expenses on labour for the waterproofing are significant compared to the basic structure except for ferrocement and micro concrete roofing. The ferrocement channel itself is highly impermeable, since it is made of rich cement sand mortar (1:2). The micro concrete tiles are inherently waterproof because of their high consolidation induced by the vibrating table during production. Therefore, it appears that the roof treatments, in general, contribute significantly to the employment generation compared to those of the basic structure of the roofing systems.

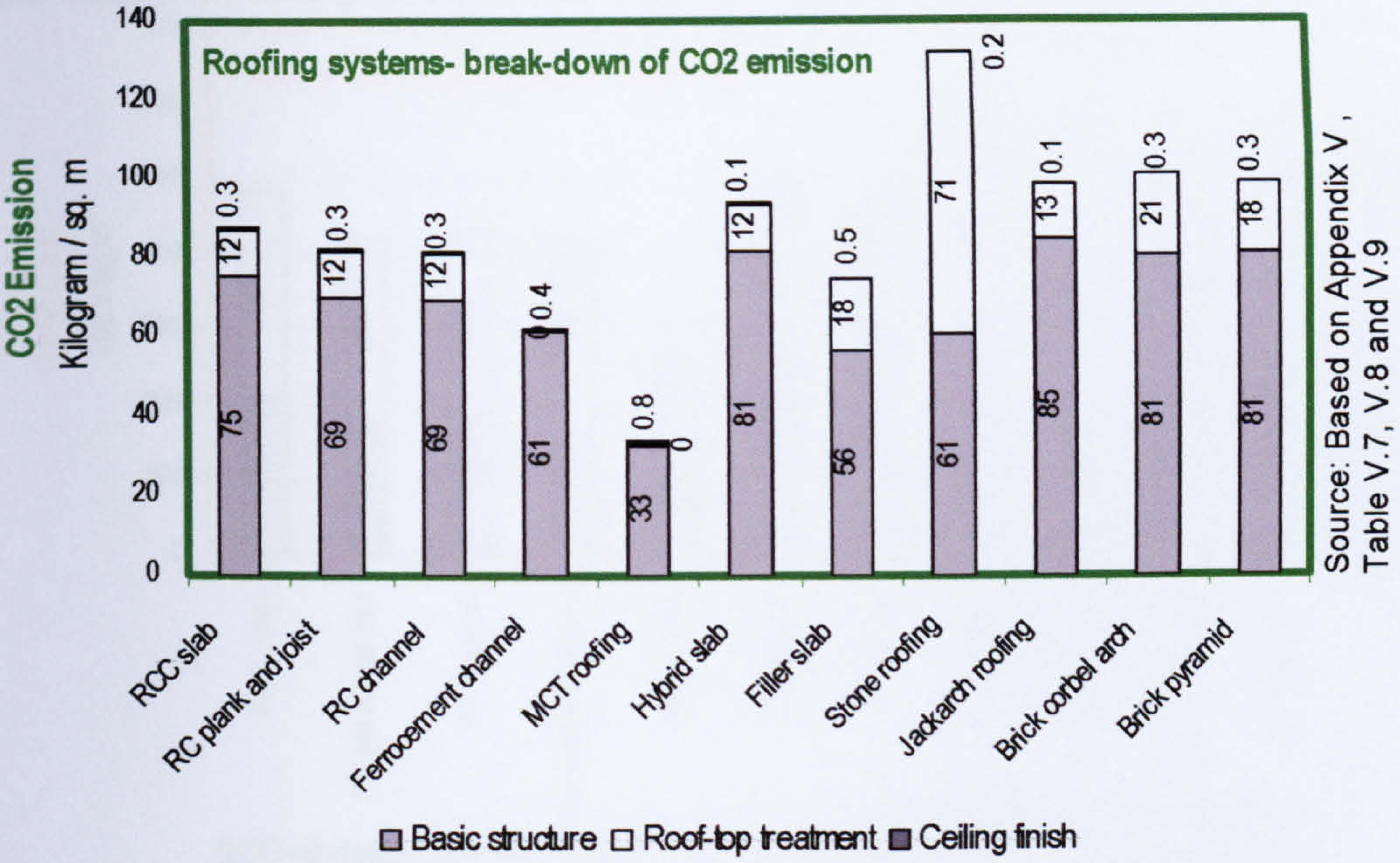
Figure 9-14: Unit embodied energy (non-renewable + renewable + waste) of the roofing systems in Mega Joules per square metre of the plan area.



RCC-reinforced cement concrete, RC- reinforced cement, MCT-micro concrete tiles

The Figure 9-14 shows that the waterproofing on the stone roofing is the most energy intensive of all the roofing options. This is owing to the use of brickbat coba as waterproofing, which is at least 115 mm thick compared to the others (usually 50 mm). In a situation where brick production is coal and firewood-based, one would have concluded that this treatment is the most detrimental to the environment. However, In Ranga Reddy district, brick was produced by using rice husk, an agriculture waste, as a fuel and hence, was environment-friendly from the point of embodied energy. Figure 9-14 shows that the combined embodied energies of the rooftop waterproofing treatments and ceiling finishes are not insignificant (except micro concrete tile roof) compared to those of the basic structures.

Figure 9-15: CO_2 emission of the roofing systems in kilograms per square metre of plan area



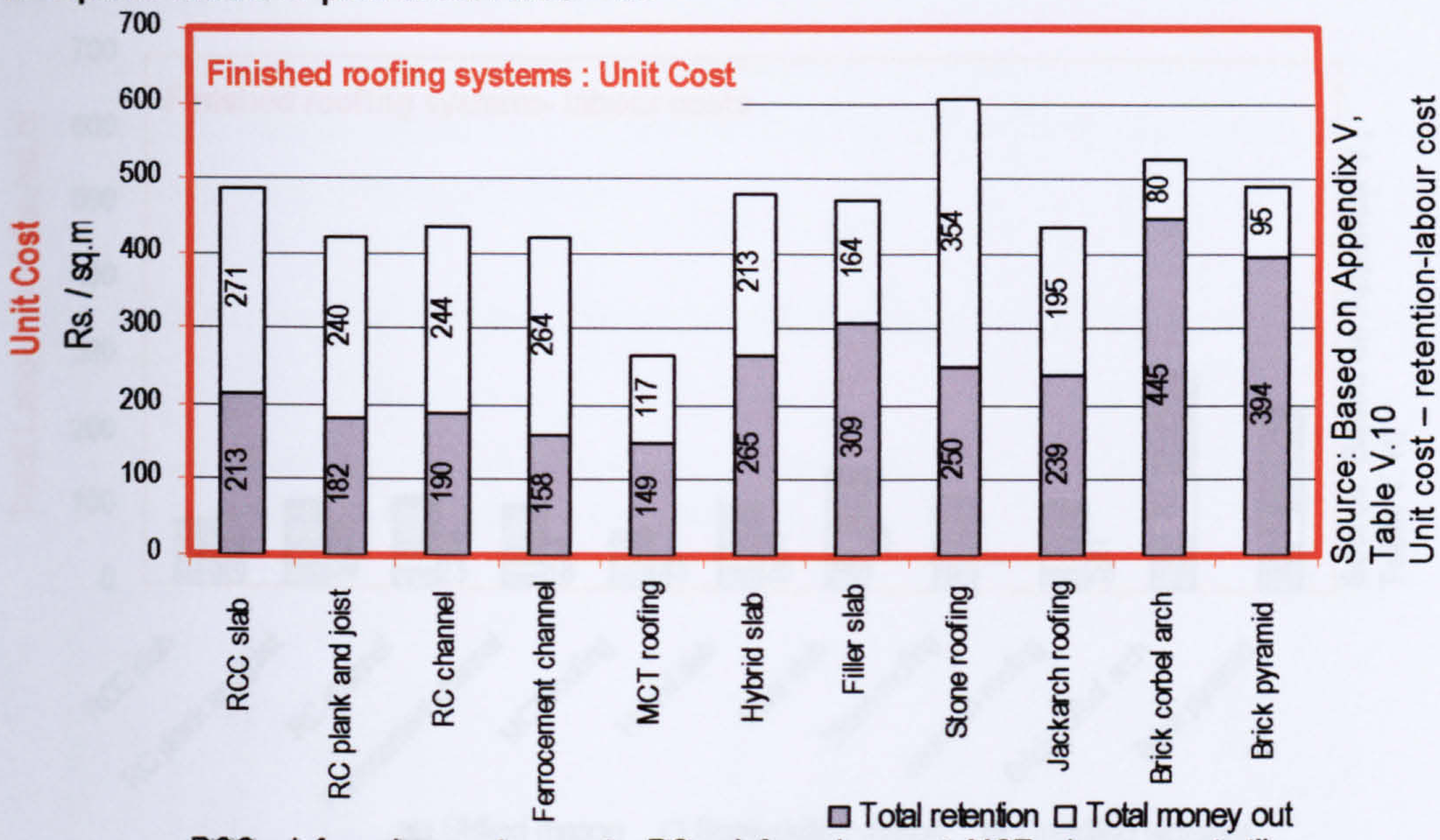
RCC-reinforced cement concrete, RC- reinforced cement, MCT-micro concrete tiles

The overall pattern of CO_2 emission of the eleven roofing systems shown in Figure 9-15 is similar to Figure 9-14 on the embodied energies. While it has been stated before that the embodied energy of brickbat coba in the context of Ranga Reddy was environment friendly, the above graph shows that, from CO_2 emission point of view, it is the most damaging to the environment. Every square metre of brickbat coba produces 71 kilograms of CO_2, which is far too high compared to the other options of rooftop treatments. The next to brickbat coba is the impervious plaster on the corbelled arch, which emits 21 kilograms of CO_2 per square metre of plan area, less than one third of the former.

9.3.4 Examining Database of Roofing as Finished Products

The section 9.3.3 has analysed the eleven roofing systems showing the significances of the socio-economic and environmental impacts of the basic structure, rooftop waterproofing and ceiling finishes. The figures below now will show the socio-economic and environmental impacts of the eleven roofing systems as finished products.

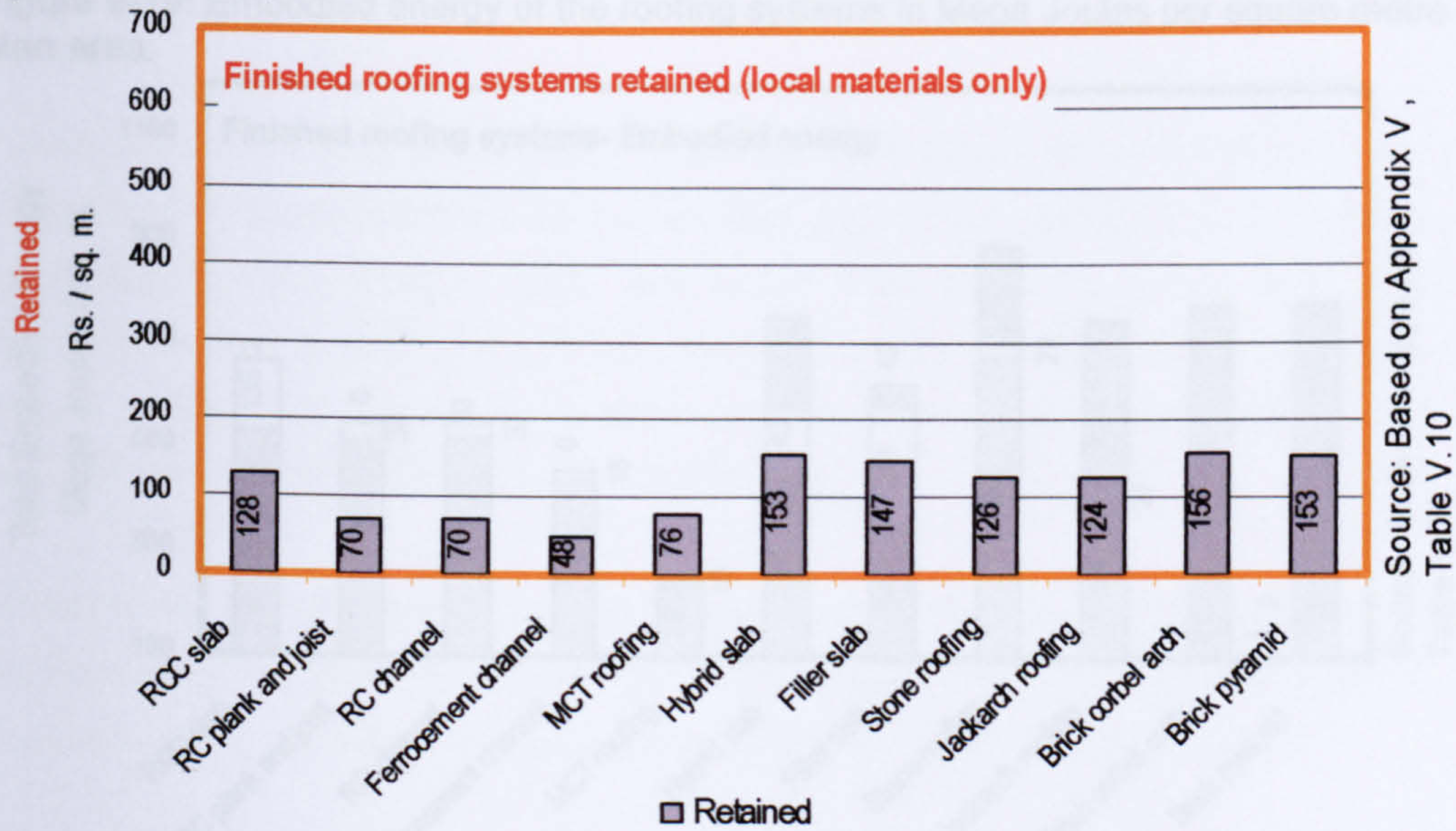
Figure 9-16: Unit costs (basic structure + finishes) of the eleven roofing systems in rupees per square metre of plan area. Rs80 = £1



RCC-reinforced cement concrete, RC- reinforced cement, MCT-micro concrete tiles

Figure 9-16 shows that micro concrete tile is the cheapest and stone roofing is the most expensive option. While brick intensive systems are expensive, they retain the highest amount of money per square metre of plan area.

Figure 9-17 Retention by the roofing systems (basic structure + finishes) in rupees per square metre of plan area. Rs80 = £1.



RCC-reinforced cement concrete, RC- reinforced cement, MCT-micro concrete tiles

Figure 9-17 shows that the use of local materials retains a significant amount of money within the district. While the roofing systems with bricks and the filler slab roofing had high retention, the pre-cast roofing systems were low in this respect.

Figure 9-18: Labour cost (basic structure + finishes) of the roofing systems in rupees per square metre of plan area. Rs80 = £1.

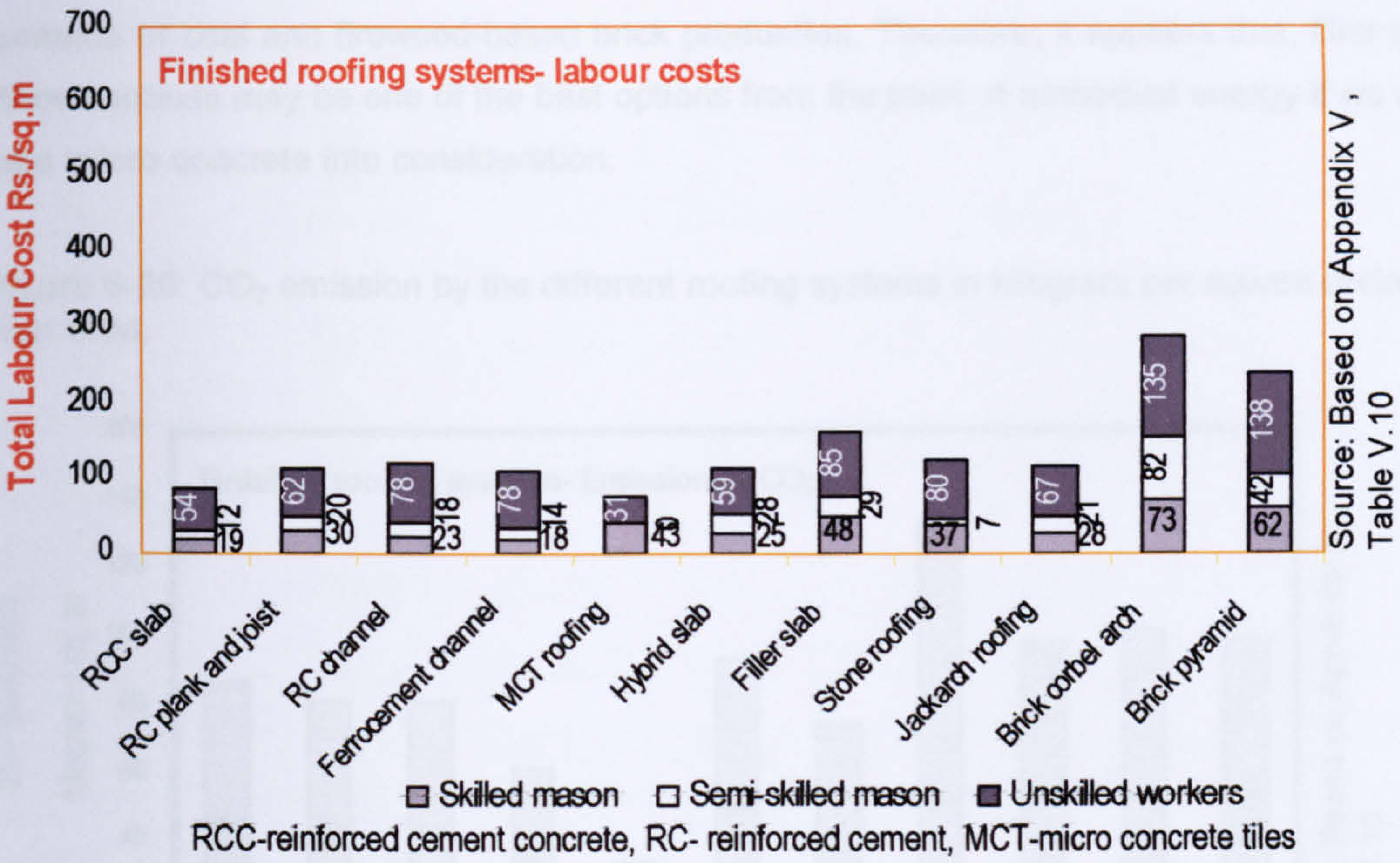
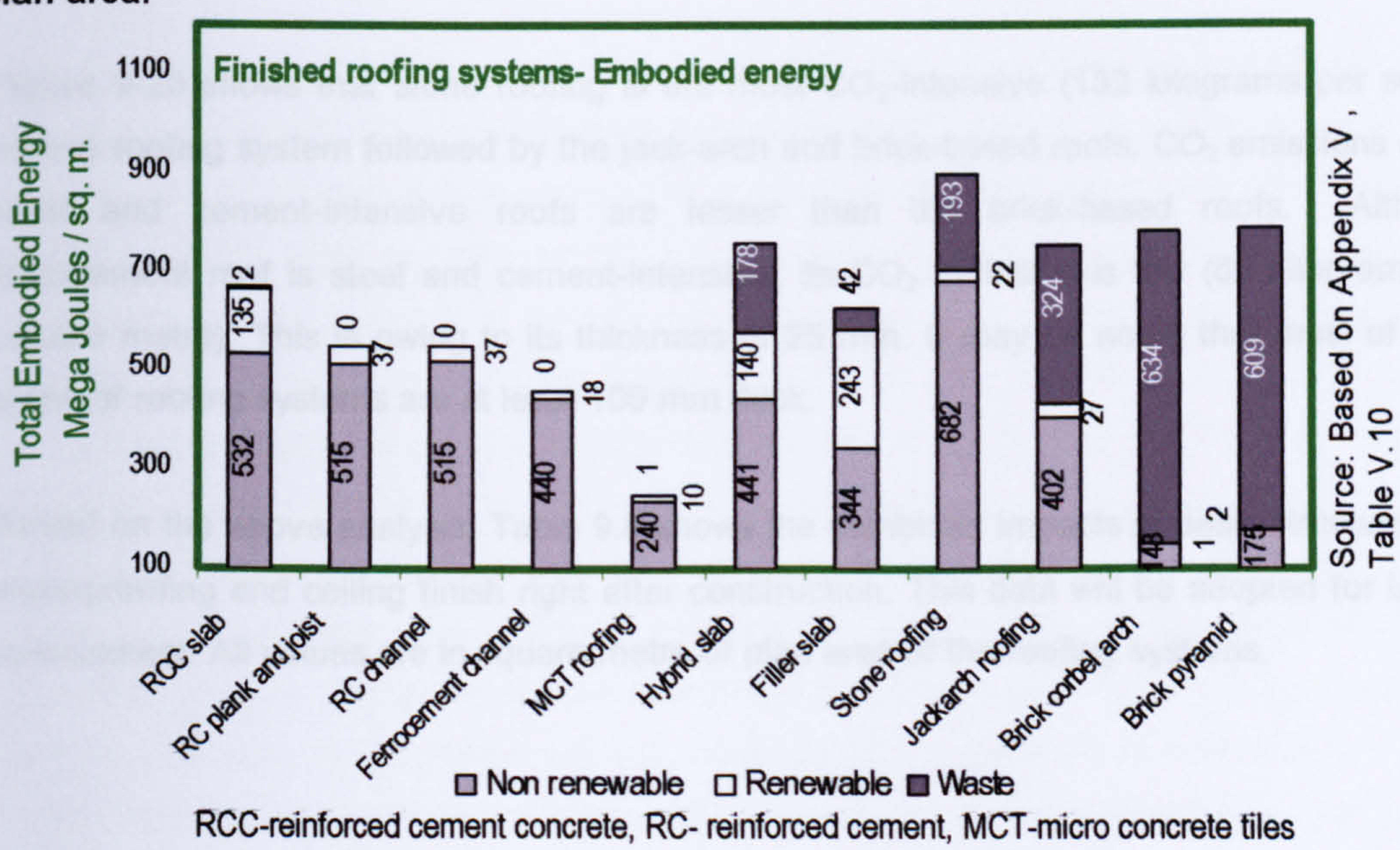


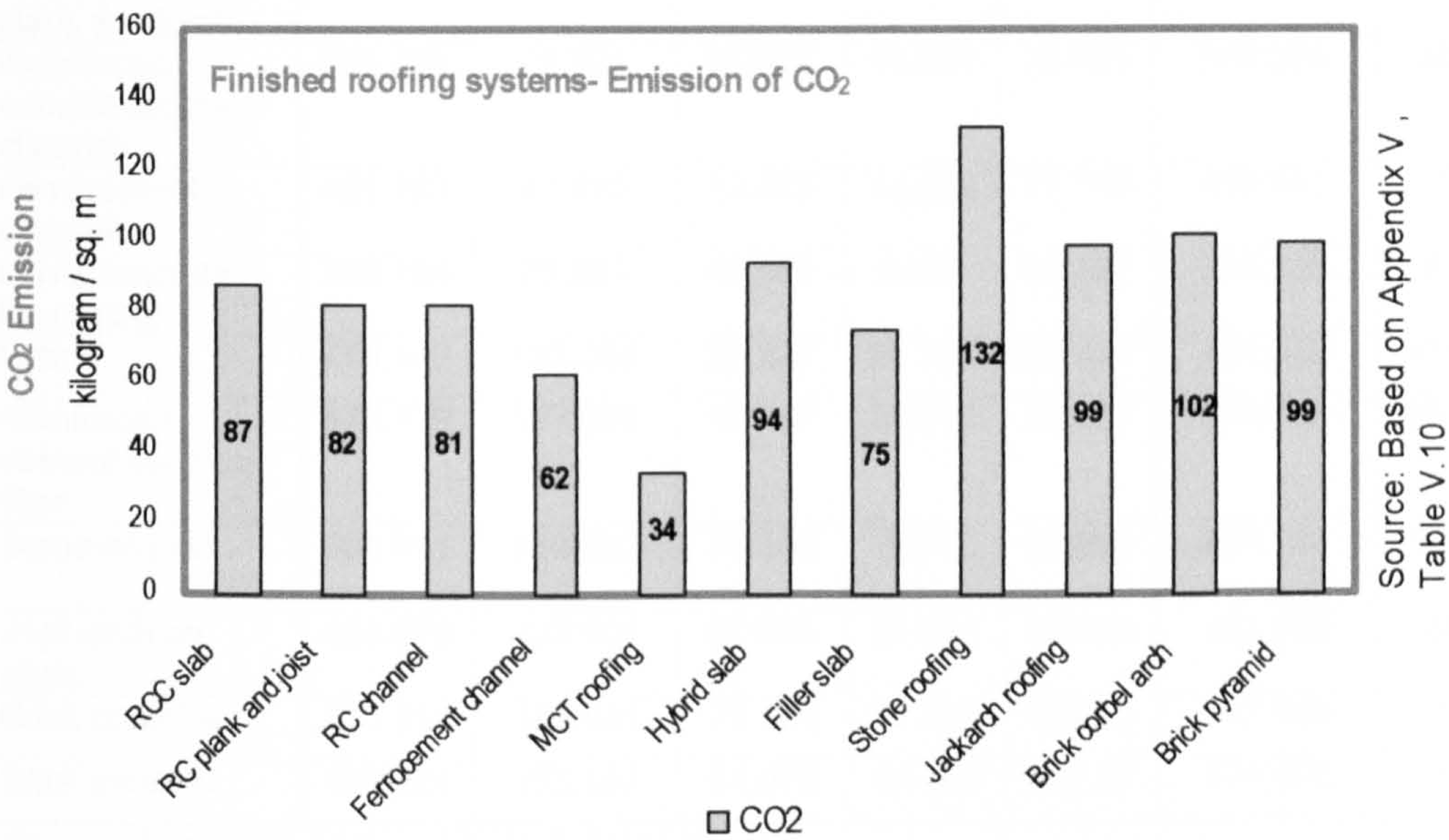
Figure 9-18 shows that the corbelled brick roofing systems are the most labour-intensive. The labour intensity of the cement and steel-intensive roofing systems are low. In general, the intensity of unskilled workers is high in most of the finished roofing system.

Figure 9-19: Embodied energy of the roofing systems in Mega Joules per square metre of the plan area.



Let us now look at the environmental impacts of the roofing systems as finished products in Figure 9-19 and Figure 9-20. Figure 9-19 shows that most of the roofing systems adopted in Ranga Reddy were highly non-renewable energy-intensive. Although the high embodied energy of the brick-intensive systems were not damaging to the environment because of the use of rice husk as fuel in Ranga Reddy, these will not be at all environment-friendly in other contexts of coal and firewood-based brick production. Therefore, it appears that, filler slab in other contexts may be one of the best options from the point of embodied energy if we do not take micro concrete into consideration.

Figure 9-20: CO_2 emission by the different roofing systems in kilogram per square metre of plan area.



RCC-reinforced cement concrete, RC- reinforced cement, MCT-micro concrete tiles

Figure 9-20 shows that stone roofing is the most CO_2-intensive (132 kilograms per square metre) roofing system followed by the jack-arch and brick-based roofs. CO_2 emissions of the steel and cement-intensive roofs are lesser than the brick-based roofs. Although ferrocement roof is steel and cement-intensive, its CO_2 emission is low (62 kilograms per square metre). This is owing to its thickness of 25 mm. It may be noted that most of other types of roofing systems are at least 100 mm thick.

Based on the above analysis, Table 9.8 shows the combined impacts of basic structure, roof waterproofing and ceiling finish right after construction. This data will be adopted for impact assessment. All values are in square metre of plan area of the roofing systems.

Table 9.8 Socio-economic and environmental impacts of the **eleven roofing systems** (basic structure + finishes). Impacts are per square metre of plan area. (Rs.80 = £1)

	Socio-economic impact					Environmental impact			
Roofing systems	**Unit cost**	**Retained**	**Skilled**	**Semi skilled**	**Un skilled**	**Non renewable**	**Re-newable**	**Waste**	**CO_2**
	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	Rs./ sq.m.	MJ/ sq.m.	MJ/ sq.m.	MJ/ sq.m.	Kg./ sq.m.
Reinforced cement concrete insitu	484.686	128.428	18.944	12.474	53.631	532.050	135.183	2.078	87.331
Reinforced cement concrete plank and joist	421.910	69.962	29.841	19.793	61.996	515.050	36.658	0.386	81.832
Reinforced cement concrete channel	433.700	70.221	23.043	18.354	78.421	515.274	36.658	0.384	81.208
Ferrocement channel	421.763	47.910	18.383	14.069	77.749	439.611	17.613	0.008	61.969
Micro concrete tile roofing	266.194	75.953	42.880	0.091	30.567	239.876	9.769	0.622	33.830
Hybrid	478.145	153.364	25.227	27.867	58.834	441.456	139.528	178.41	93.548
Reinforced cement concrete filler	473.179	147.028	47.797	28.549	85.377	343.828	242.668	41.999	74.775
Stone on joist	604.411	126.322	36.536	7.217	80.350	681.723	21.870	192.543	132.050
Jack-arch on joists	433.676	123.904	27.608	20.974	66.545	402.352	26.891	323.56	98.635
Brick corbel arch	525.314	155.991	72.859	81.748	134.73	147.900	1.498	633.54	101.72
Brick pyramid	489.024	153.157	61.679	41.663	137.57	174.898	1.727	609.48	99.304

Source: Adopted from Appendix V, Table V.10

Chapter 8 has shown the process of data collection and has presented the data for the all nine socio-economic and environmental parameters belonging to the level-1 materials. The second part of chapter 8 has shown the socio-economic and environmental data of the level-2 materials which are all pre-cast. This chapter has shown the impacts of the six walling and eleven roofing systems on the socio-economic and environmental aspects with respect to the village Jaggamguda in Ranga Reddy district. It may be reiterated that comparing walls and roofs separately will not help the decision makers, since the wall heights required for the different roofs are different. Therefore, a walling technology which is expensive may workout to be economic if it is combined with a particular sloping roof for which the wall height required is 2.1 metres. This has been explained in chapter 5 on Andhra Pradesh Primary Education Project. Therefore, it is necessary to study the impacts for different combinations of walls and roofs. In the present context, there are 66 combinations of walls and roofs and it is assumed that all of them are feasible as with the Ranga Reddy district. Therefore, the next chapter will carry out the impact assessment of all the 66 walling and roofing combinations based on the data in Table 9.4 and Table 9.8.

CHAPTER 10 : IMPACT ASSESSMENT

Chapter 3 of this dissertation was on the need assessment of the basic minimum services, i.e., primary education, primary health care and housing in India. It revealed that poverty is a crucial issue in this country and infrastructure supply could be an opportunity for income generation. Chapter 4 has examined the context of social infrastructure development and poverty in India. While developing a strategy for sustainable social infrastructure in line with the international guidelines, it was found that the international communities are very much concerned about the environmental degradation from increased human activities in which construction has a very significant role. Hence, the role of various construction technologies as opportunities for income generation and environmental degradation have been examined in the context of the DFID-funded Andhra Pradesh Primary Education Project in Ranga Reddy district, where various types of construction technologies were adopted to construct new school buildings at 29 sites.

While a construction technology with low life cycle cost is preferable, it has been found that some technologies are more labour-intensive than others, e.g., rat-trap compared to solid brick wall (explained in chapter 4). It has also been seen that the use of local materials in construction retains more money at micro level and benefit the local building material manufacturers and suppliers compared to the cement and steel intensive systems. Therefore, while attempting to create social infrastructure with low life cycle cost, the decision makers need to review the issue of construction as an opportunity for income generation to help in poverty reduction, which is a priority at global level. However, construction could also be a threat on the environment, if non-renewable energy-intensive building materials are used in social infrastructure creation. The CO_2 emission of the construction technologies could also be damaging to the environment. Therefore, there is a need for analysing these issues so that the decision makers can study the implications of using different construction technologies in a context and can make sustainable decisions. With this intention, an impact assessment tool and evaluation method has been developed in chapter 7. The impact assessment needs data to demonstrate the implications. Therefore, the collection process and the calculation of actual values of the data have been shown in chapter 8 and 9. In this chapter, we shall study the impacts based on the level 3 data, i.e., the finished walls and roofs, which are based on Level 1 and 2 data.

Irurah and Holm (1999), while discussing the short comings of the energy-intensity approach, state that Haseltine (1975) has correctly argued that some materials have been 'falsely presented' as being energy efficient merely on the basis of their energy-intensity without any regard to the quantities of materials consumed. He argued that it will be appropriate to compare energy-intensity between building construction systems rather than between materials. In the present context, combinations of different walling systems have been adopted to assess the realistic energy-intensity. In the previous chapter, it has been shown that, even in case of unit cost, comparing between unit cost of wall and roof is misleading.

It may be reiterated that this dissertation is not an attempt towards providing optimised solutions on construction technologies in a particular location. It explains the socio-economic and environmental impacts of different construction technologies with reference to an example, viz., the District Primary Education Programme. Under this programme, 27 billion rupees (£0.34 billion) was spent for primary school construction in 271 districts over 18 states, i.e., approximately 100 million rupees (£1.25 million) per district. In this chapter, the impact assessment of investing 100 million rupees in a district has been carried out so that the decision makers can see the quantitative implications of the project as a whole. For example, it will show how many working days of employment will be generated by adopting a particular combination of walling and roofing technologies in a project. It is, therefore, more of a process study rather than providing a fixed end-result. Before embarking on the impact assessment, the domain of the study has been defined by stating the assumptions as follows.

10.1. THE ASSUMPTIONS

- All the data are based on Jaggamguda, a village in Ranga Reddy district of Andhra Pradesh, India. The pre-cast elements have been assumed to be produced at Aliabad, a village two kilometres from Jaggamguda and hence, the same lead chart as shown in Figure 1.9 (chapter 1) has been adopted for both. However, impacts owing to transportation of the pre-cast elements from Aliabad to Jaggamguda have been considered.

- As mentioned in chapter 1, the foundation has been excluded from the domain of impact assessment.

- Chapter 1 mentions that the finishing items such as doors, windows and flooring, etc., have also been excluded from the domain of analysis.

- The assumed plan-form is square and the site is on a flat land and not low lying.

- The impact assessment will be based on the different combinations of walling and roofing systems of a classroom with 5.5 metres x 5.5 metres internal dimensions. It has already been discussed that the flat roofs require a floor to ceiling height of 3 metres and hence, the wall height also has to be the same. In case of the sloping roofs, since the height of the room in the centre is 3.5 – 4.2 metres, the wall height could be between 2.7 and 1.8 metres.

- The covered areas have been calculated according to the respective wall thicknesses of different walling systems, which vary between 150 mm and 380 mm. Deductions for doors and windows have been ignored and the impact assessment has been carried out for the 66 combinations of 11 roofing and 6 walling systems.

- The Andhra Pradesh Primary Education Project and Repair and Upgrading programme revealed that the construction workers enjoyed relaxing, playing cards and above all took part in many festivals, both religious and secular. Every month there was a "Sankranti", i.e., the change of zodiac, when the construction workers took part in rituals for two days, which affected the site works. Apart from that, on the occasion of new moon and full moon, people did not work. It is interesting to note that the Hindu, Muslim and Christian masons celebrated all the religious events. They always looked for an opportunity to celebrate. Sometimes, to keep the site work going during the celebration time, the workers were offered double the wages, which did not attract them at all and they declined them. Under such circumstance it may be reasonable to assume five days a week for fifty two weeks, i.e., 260 working days in a year. This has been assumed as a construction workers' working year.

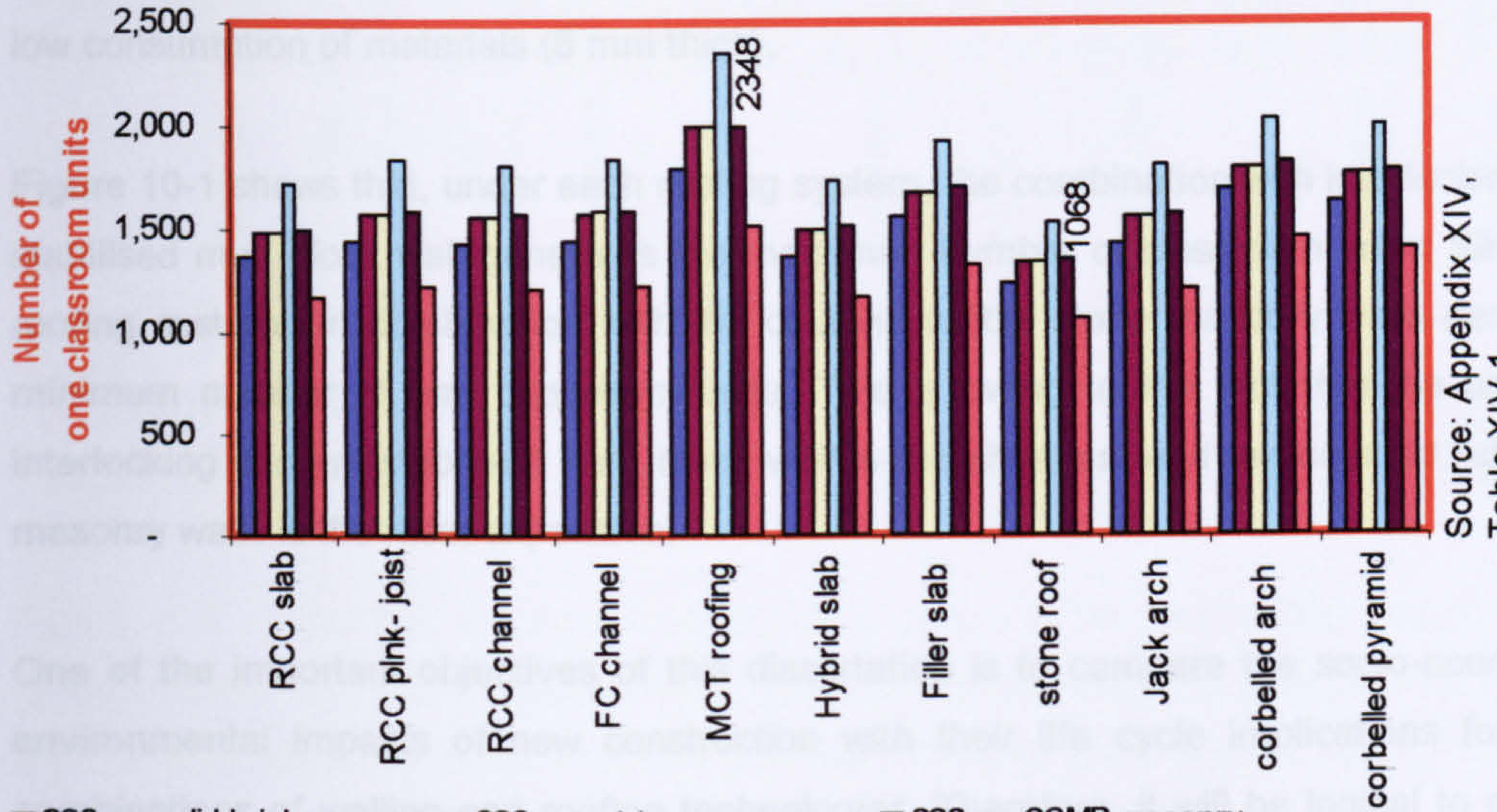
- A reinforced cement concrete band lintel has been assumed at door/window top level of the classroom.

10.2. THE SOCIO-ECONOMIC IMPACTS

As mentioned in the beginning of this chapter, the example of District Primary Education Programme will be used for demonstrating the socio-economic and environmental impacts. Under this programme, a detailed need assessment for education infrastructure was carried out at district level to give access to all the children of age between 6 and 11 years. However, the required amount of money could not be provided owing to financial constraints and 100 million rupees (£1.25 million) per district was allocated for the construction of new schools, additional classrooms, etc. It may be noted that the money for the programme was mostly based on a loan from the World Bank. Therefore, the decision makers had to expedite other sources of funding under different rural development programmes. The most crucial question in District Primary Education Programme was "how much floor area could be constructed out of 100 million rupees"? Therefore, economy was a very important issue (DPEP, 1995).

Let us now examine the actual impacts of investing 100 million rupees (£1.25 million) at district level. As shown in chapter 5, the walling and roofing systems, on an average, costs 58% of the total cost of a classroom. Therefore, 58 million rupees (£0.73 million) out of 100 million rupees has been considered as the cost of wall and roof. Based on this budget, the database (chapter 9) on cost of the different walling and roofing technologies have been adopted for calculating the total number of one classroom units, each having carpet area of 5.5 metres x 5.5 metres.

Figure 10-1 The number of classrooms that could be constructed with 100 million rupees, using 66 combinations walling and roofing technologies. Rs80 = £1.



230mm solid brick masonry | 230mm rat-trap masonry | 230mm CSMB masonry
150mm ICSMB masonry | 190mm SCB masonry | 380mm CRS masonry

RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Table 10.1 The two combinations of walling and roofing systems, with which the maximum and minimum number of classroom units could be constructed by investing 100 million rupees in a district. Rs80 = £1.

	Number of one classroom units	Walling systems	Roofing systems
Maximum	2348	150 mm interlocking cement stabilised mud block masonry	Micro concrete tile roof with steel and timber under-structure
Minimum	1068	380 mm coursed rubble stone masonry	Stone roofing on pre-cast reinforced cement concrete joists

Figure 10-1 shows that by spending 100 million rupees (£1.25 million) the maximum number (2,348) of classrooms could be constructed with micro-concrete tile roofing and interlocking cement stabilised mud block wall. The most noticeable feature of the Figure 10-1 is the huge difference between maximum and minimum number of one classroom units. The maximum number, with micro concrete tile roof, is more than double the minimum, which has a stone roof that is thermally superior to the former. Therefore, the decision makers will have to decide whether they should provide thermally less-comfortable schools for a large number of school children, or they should go for more comfortable classrooms for some and keep the rest without any school (temporarily).

The combination of stone roofing and coursed rubble stone masonry wall is the most expensive technological options, which is owing to the high unit cost of brickbat coba as a waterproofing treatment. Similarly the combination of micro concrete tile roofing with interlocking cement stabilised mud block is the cheapest since this type of roofing does not need any waterproofing treatment and also owing to the fact that micro concrete tiles have low consumption of materials (8 mm thick).

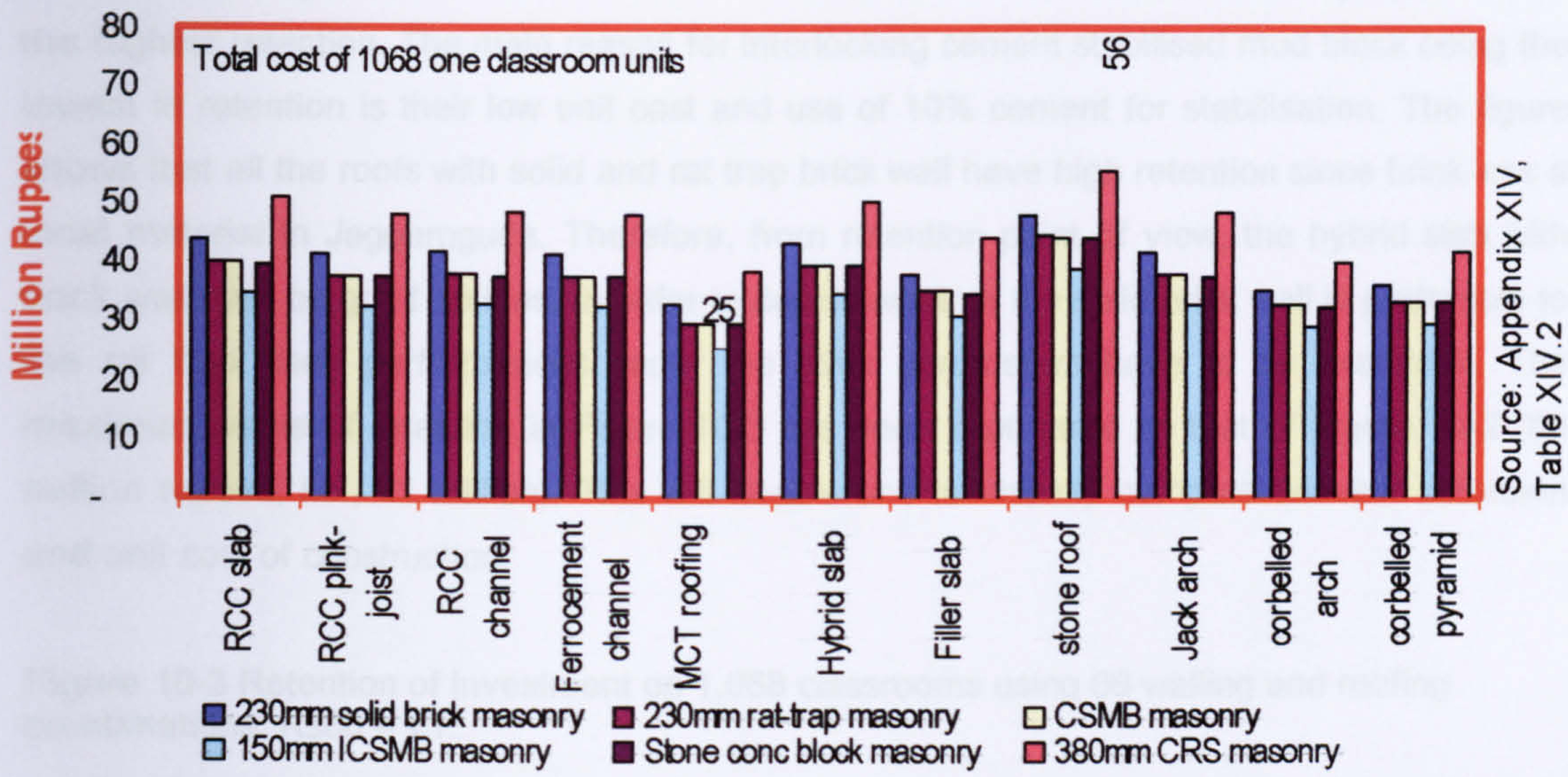
Figure 10-1 shows that, under each roofing system, the combination with interlocking cement stabilised mud block wall generates the maximum number of classroom units. Similarly the roofing systems in combination with the coursed rubble stone masonry walls generate the minimum number of one classroom units. This is owing to the fact that the unit cost of interlocking cement stabilised mud block wall is the cheapest and the coursed rubble stone masonry walls is the most expensive.

One of the important objectives of this dissertation is to compare the socio-economic and environmental impacts of new construction with their life cycle implications for different combinations of walling and roofing technologies. Therefore, it will be logical to compare a number of one classroom units adopting a combination of wall and roof with the same number of one classroom units adopting a different combination of wall and roof. The study will show the extent of differences in impacts of the two types of technologies after 50 years.

On this issue, one may argue that the basis of comparing different combinations of walls and roofs could have been in terms of one classroom. However, it may be noted that the decision makers will be able to understand the scale of impacts and will be able to relate to the ground reality if they can see the impacts of a large number of single classrooms in a district. Therefore, in this chapter, the least number of one classroom units (i.e.,1,068) has been adopted for studying the impacts on the nine socio-economic and environmental parameters. The main idea was that if this number is adopted, then even the most expensive combination could be built within 58 million rupees (£0.73 million). The following figure shows the different construction costs of 1,068 classroom units.

UNIT COST

Figure 10-2 The costs of 1068 classrooms using 66 walling and roofing combinations. Rs80 = £1



RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

Figure 10-2 shows that the most cost effective option is the interlocking cement stabilised mud block wall with micro concrete roof. The brick-intensive roofing systems with interlocking cement stabilised mud block walls are also very close to the cheapest option. Each roofing system with rat trap and cement stabilised mud block walls have similar costs since the unit costs of these two walls are almost the same. The filler slab roofing is next to the brick roofing systems. Therefore, it appears that the rat-trap, stone concrete block and cement stabilised mud block walls are very close to each other in terms of unit costs. Among the roofs, filler slab and the corbelled arch and pyramids are worth considering along with micro concrete tile roofing. Considering so many options of walls and roofs, the decision makers will have to look at the other issues of the socio-economy and environment to select the most appropriate systems.

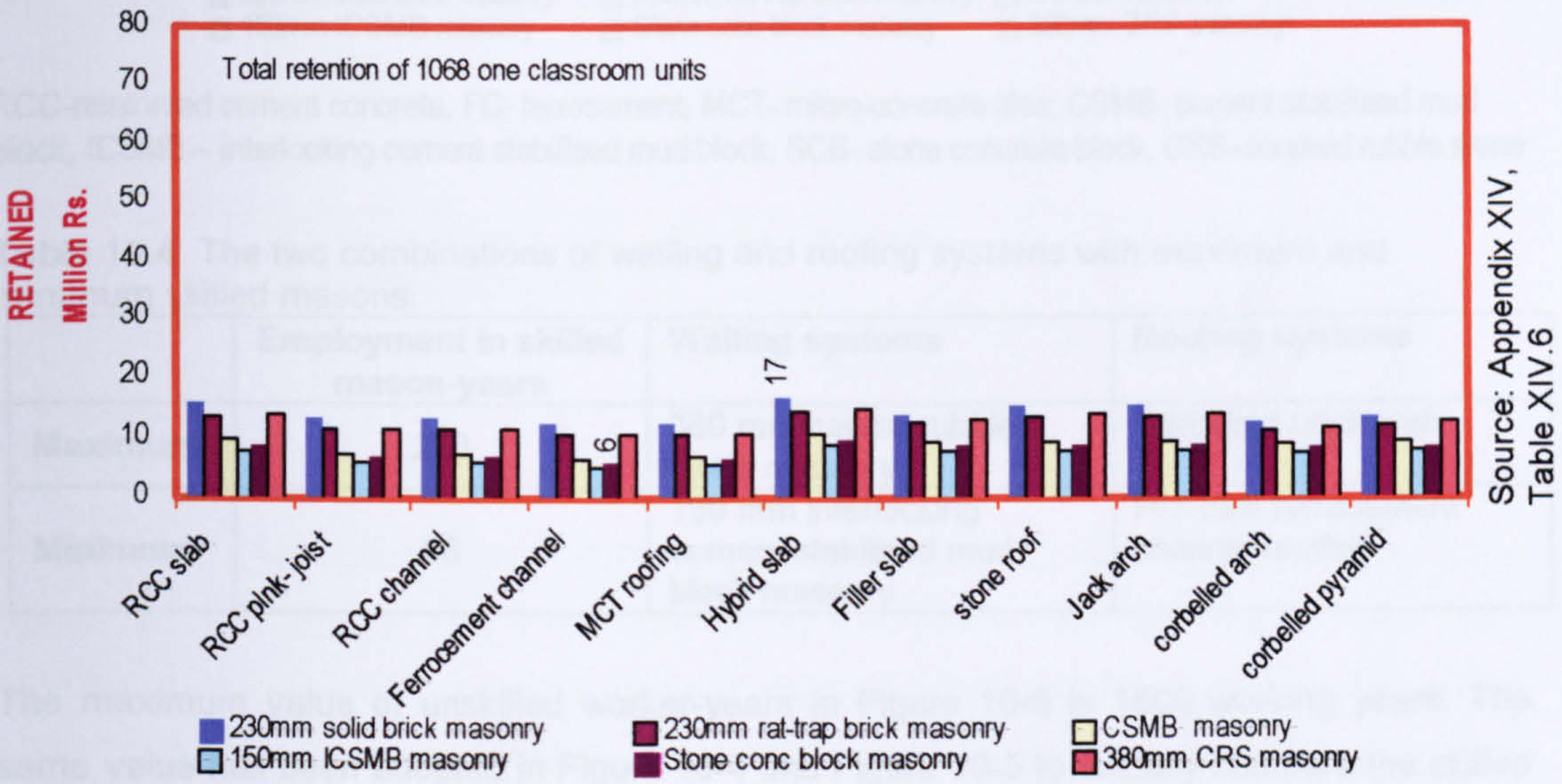
Table 10.2 The two combinations of walling and roofing systems, with maximum and minimum costs of construction. Rs80 = £1.

	Cost in million rupees	Walling systems	Roofing systems
Maximum	56	380 mm coursed rubble stone masonry	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	25	150 mm interlocking cement stabilised mud block masonry	Micro concrete tile roof with steel and timber under-structure

RETENTION

The retention here means the amount of money that is spent on the local materials used in construction. Figure 10-3 shows that the combination of solid brick wall and hybrid slab has the highest retention. The main reason for interlocking cement stabilised mud block being the lowest in retention is their low unit cost and use of 10% cement for stabilisation. The figure shows that all the roofs with solid and rat trap brick wall have high retention since brick was a local material in Jaggamguda. Therefore, from retention point of view, the hybrid slab with brick walls will be good options. In order to decide whether the solid brick wall is preferable to the rat trap, their performances under the other parameters have to be examined. The maximum value of retention in Figure 10-3 has been kept same as that of Figure 10-2 (80 million rupees, i.e., £1 million). This will enable one to visually compare between retention and unit cost of construction.

Figure 10-3 Retention of investment on 1,068 classrooms using 66 walling and roofing combinations. Rs80 = £1.



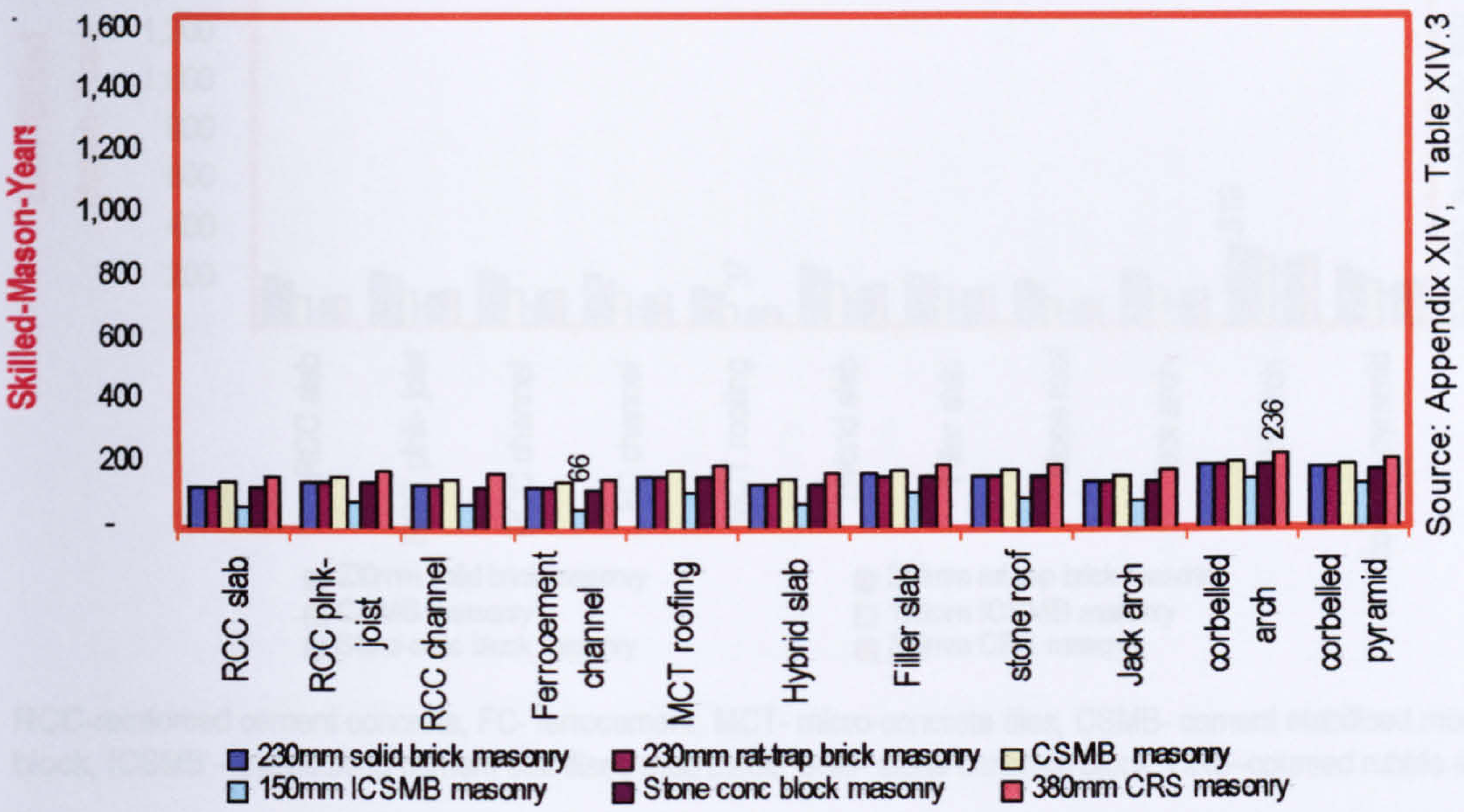
RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

Table 10.3 The two combinations of walling and roofing systems having maximum and minimum retention. Rs80 = £1.

	Retention in million rupees	Walling systems	Roofing systems
Maximum	17	230 mm solid brick wall	Hybrid slab
Minimum	6	150 mm interlocking cement stabilised mud block masonry	Pre-cast ferrocement channel roofing

LABOUR INTENSITY

Figure 10-4 Skilled-mason-years of employment generated by the investment on 1,068 classrooms using 66 walling and roofing combinations



RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

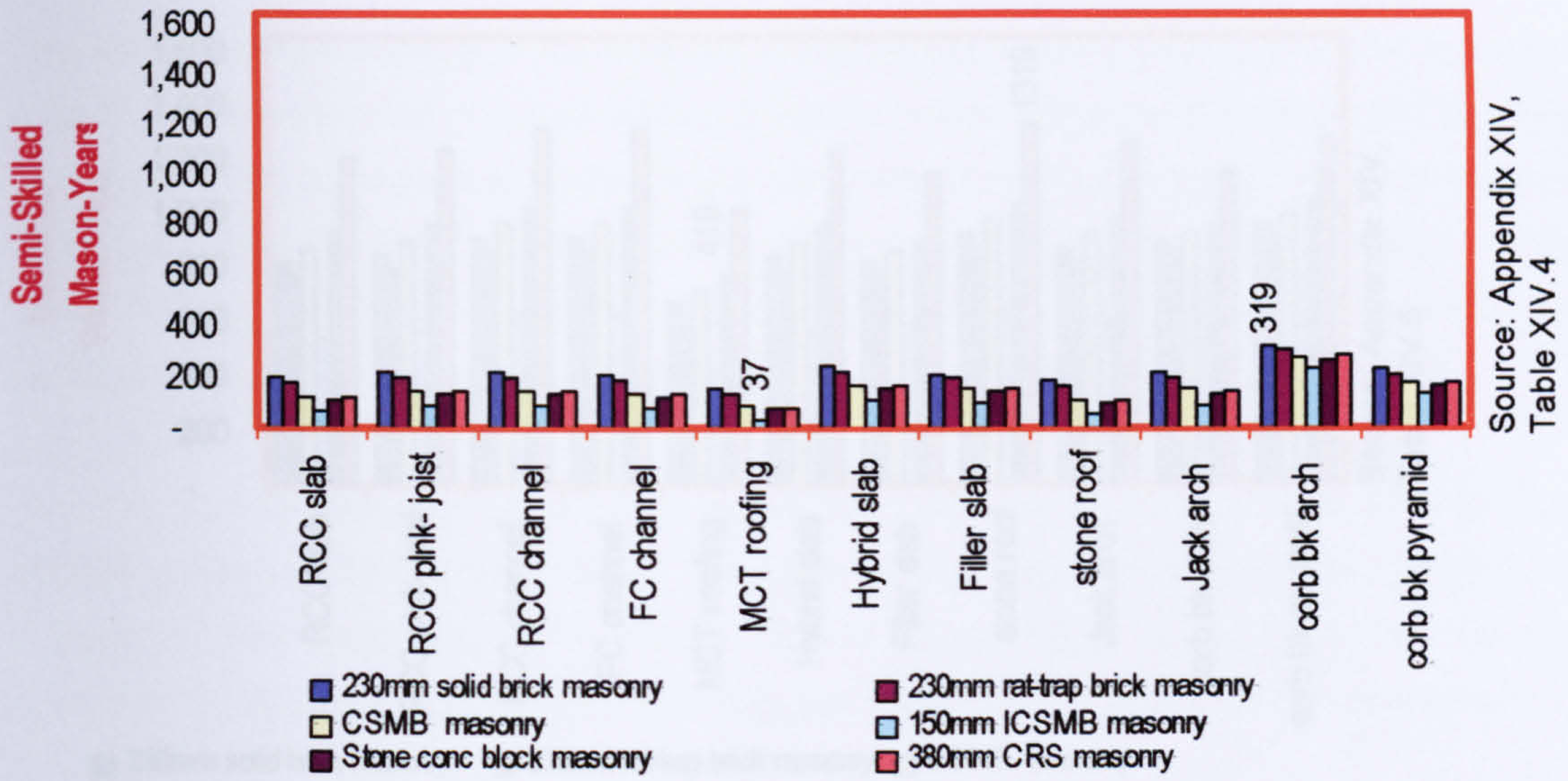
Table 10.4 The two combinations of walling and roofing systems with maximum and minimum skilled masons.

	Employment in skilled mason-years	Walling systems	Roofing systems
Maximum	236	380 mm course rubble stone masonry	Corbelled brick arch
Minimum	66	150 mm interlocking cement stabilised mud block masonry	Pre-cast ferrocement channel roofing

The maximum value of unskilled worker-years in Figure 10-6 is 1600 working years. The same value has been adopted in Figure 10-4 and Figure 10-5 to visually compare the skilled and semi-skilled mason intensities with that of unskilled. Figure 10-4 shows that all roofing systems in combination with cement stabilised mud block and coursed rubble stone masonry are skilled-mason intensive. Corbelled brick arch roofing in combination with coursed rubble masonry came out to be the most skilled-mason intensive. The level of skilled-mason intensity is low for all the roofs with interlocking cement stabilised mud block masonry.

Table 10.4 shows the most and the least skilled mason-intensive combinations. The combination of 380 mm thick coursed rubble stone masonry with corbelled brick arch roof is 3.6 times more skilled-mason intensive than interlocking cement stabilised mud block wall with pre-cast ferrocement channel roofing. Therefore, the decision makers have to probe into the local context to decide whether it would be socially relevant to recommend the stone wall and corbelled roof, which employs a large number of skilled masons by giving them an opportunity to improve their skills further.

Figure 10-5 Semi-skilled mason-years of employment generated by the investment on 1,068 classrooms using 66 walling and roofing combinations



RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

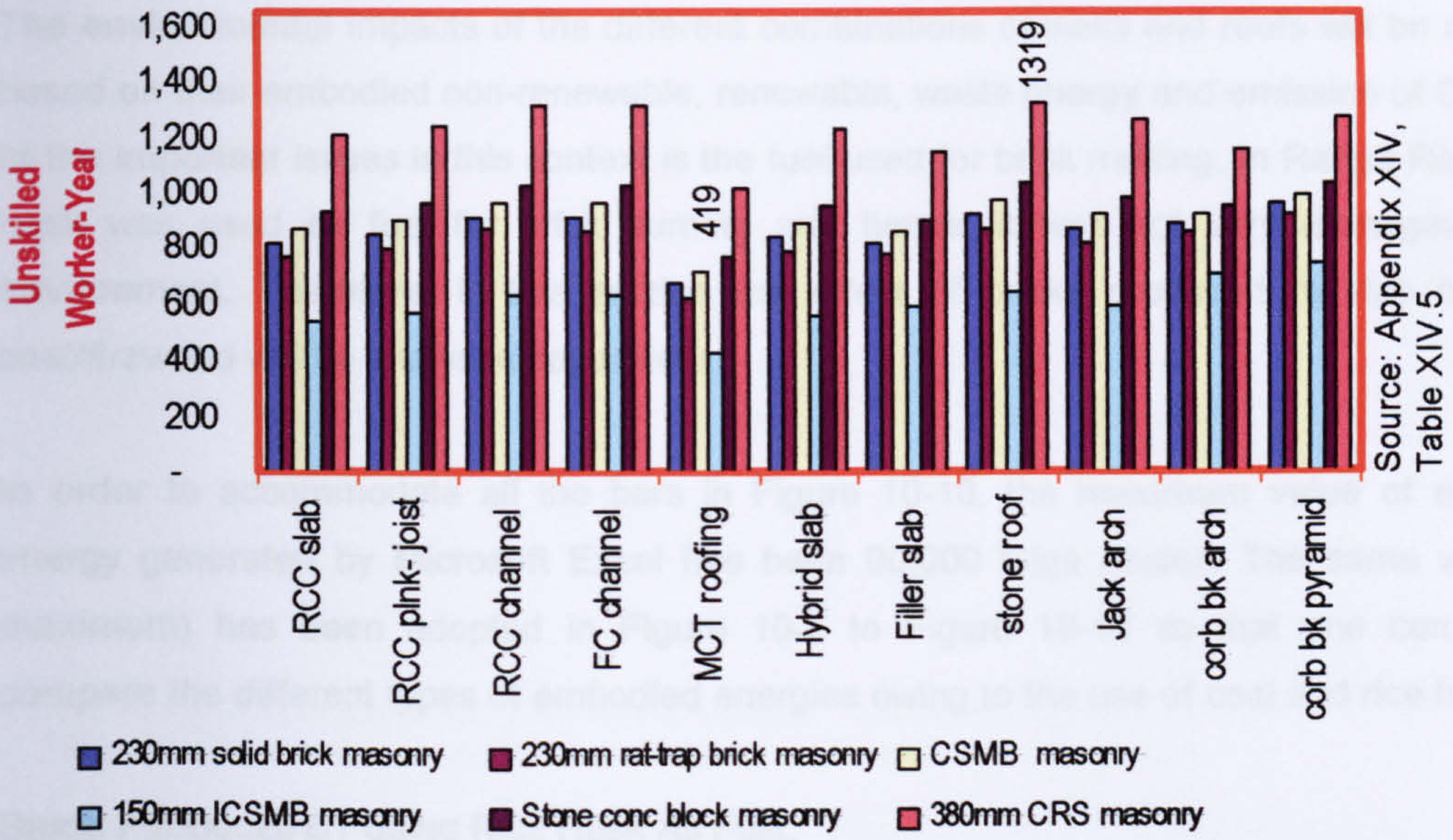
Table 10.5 The two combinations of walling and roofing systems with maximum and minimum employment opportunities for the semi-skilled masons.

	Employment in semi-skilled-mason-years	Walling systems	Roofing systems
Maximum	319	230 mm solid brick wall	Corbelled brick arch
Minimum	37	150 mm interlocking cement stabilised mud block masonry	Micro concrete tile roof with steel and timber under-structure

All the roofing combinations with 230 mm solid brick masonry wall have high semi-skilled mason intensity. Figure 10-5 shows that all the walls with corbelled brick arch roof have higher semi-skilled mason intensity than the rest of the combinations. Based on Figure 10-4 and Figure 10-5, it may be said that, by recommending brick-intensive walls and corbelled brick arch roof in a particular context, both skilled and semi-skilled masons' employment opportunities could be increased.

However, by comparing the Figure 10-4 to Figure 10-6, it may be said that the intensity of unskilled workers was high in the construction technologies adopted in Ranga Reddy district. While a maximum of 236 skilled mason-years and 319 semi-skilled mason-years could be generated by constructing 1,068 one classroom units, the minimum unskilled worker-years are 419. The following figure shows that the roofing combinations with coursed rubble stone masonry generate very high unskilled worker-years compared to the other options. All the roofing systems in combinations with interlocking cement stabilised mud block wall generate very low number of unskilled worker-years.

Figure 10-6 Unskilled worker-years of employment generated by the investment on 1,068 classrooms using 66 walling and roofing combinations



RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

Table 10.6 The two combinations of walling and roofing systems with maximum and minimum unskilled workers.

	Employment in unskilled worker-years	Walling systems	Roofing systems
Maximum	1319	380 mm coursed rubble stone masonry	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	419	150 mm interlocking cement stabilised mud block masonry	Micro concrete tile roof with steel and timber under-structure

The above analysis on the labour intensities of skilled, semi-skilled and unskilled construction workers generated by different combinations of walls and roofs will help the decision makers to choose an appropriate combination if they are aware of the employment status of a particular context. It depends upon the Government's strategy on employment as well. However, in the context of Ranga Reddy district, recommending the corbelled brick arch roof with coursed rubble stone wall may be beneficial to the local construction workers.

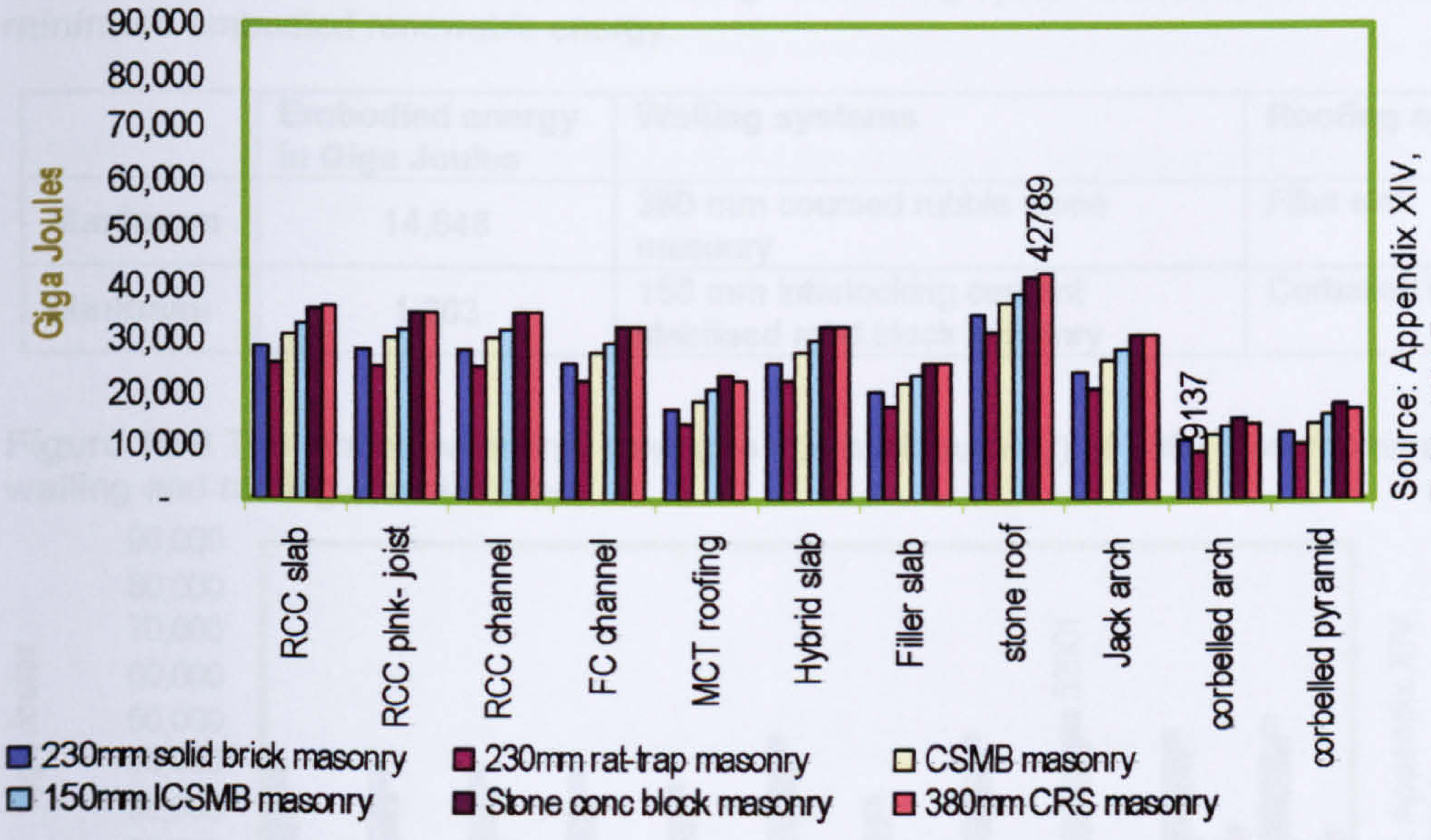
10.3. ENVIRONMENTAL IMPACTS

The environmental impacts of the different combinations of walls and roofs will be assessed based on their embodied non-renewable, renewable, waste energy and emission of CO_2. One of the important issues in this context is the fuel used for brick making. In Ranga Reddy, rice husk was used as fuel for brick burning and hence, it was not very damaging to the environment. Therefore, in this section the effect of bricks produced by rice husk and coal/firewood will be analysed separately.

In order to accommodate all the bars in Figure 10-10, the maximum value of embodied energy generated by Microsoft Excel has been 90,000 Giga Joules. The same value (as maximum) has been adopted in Figure 10-7 to Figure 10-12 so that one can visually compare the different types of embodied energies owing to the use of coal and rice husk.

BRICK PRODUCED BY USING RICE HUSK AS FUEL

Figure 10-7The non-renewable embodied energies of 1,068 classrooms using 66 walling and roofing combinations.

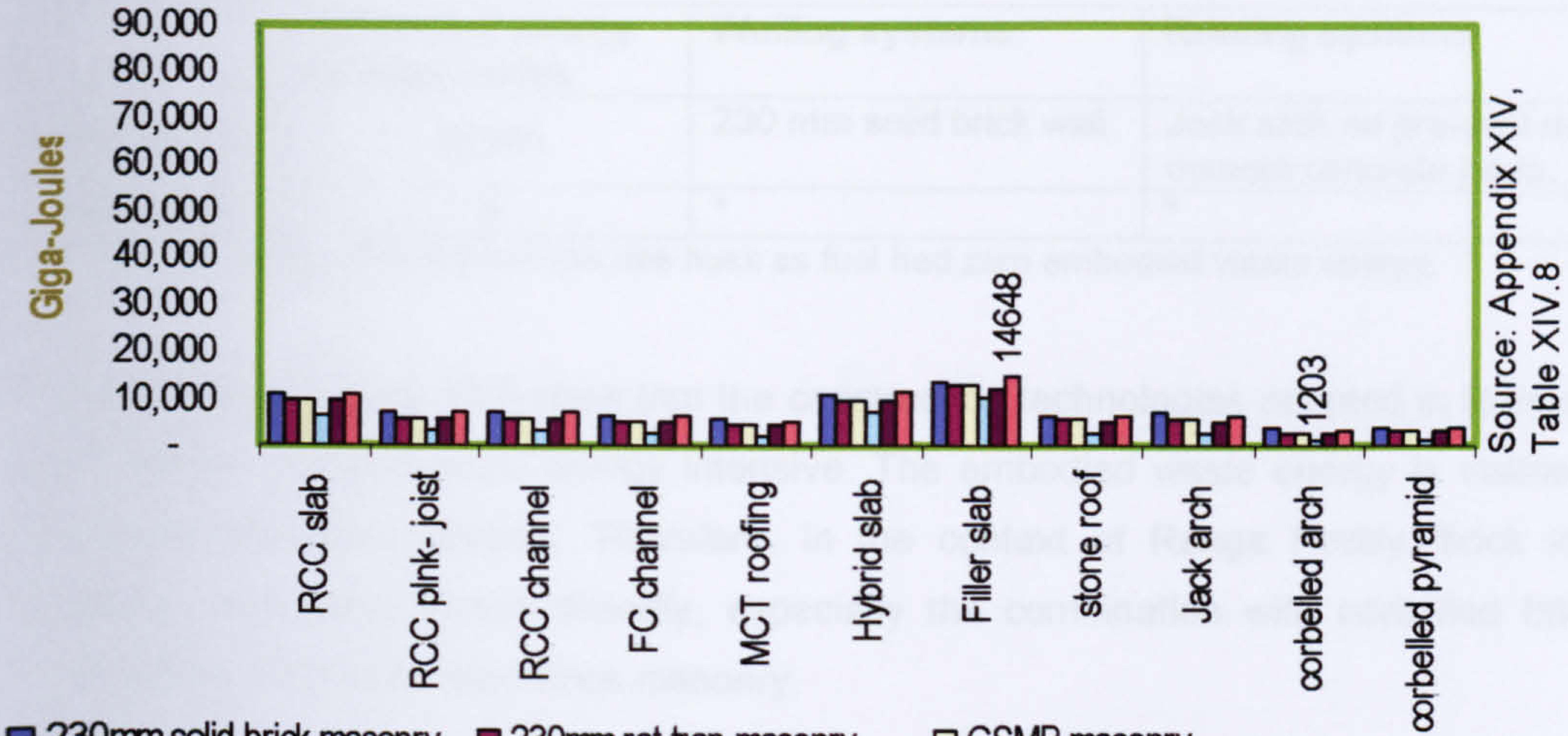


RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

Table 10.7 The two combinations of walling and roofing systems with maximum and minimum embodied non-renewable energy

	Embodied energy in Giga Joules	Walling systems	Roofing systems
Maximum	42,789	380 mm course rubble stone masonry	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	9,137	230 mm rat trap bonded brick masonry	Corbelled brick arch

Figure 10-8 The renewable embodied energy of 1,068 classrooms using 66 walling and roofing combinations

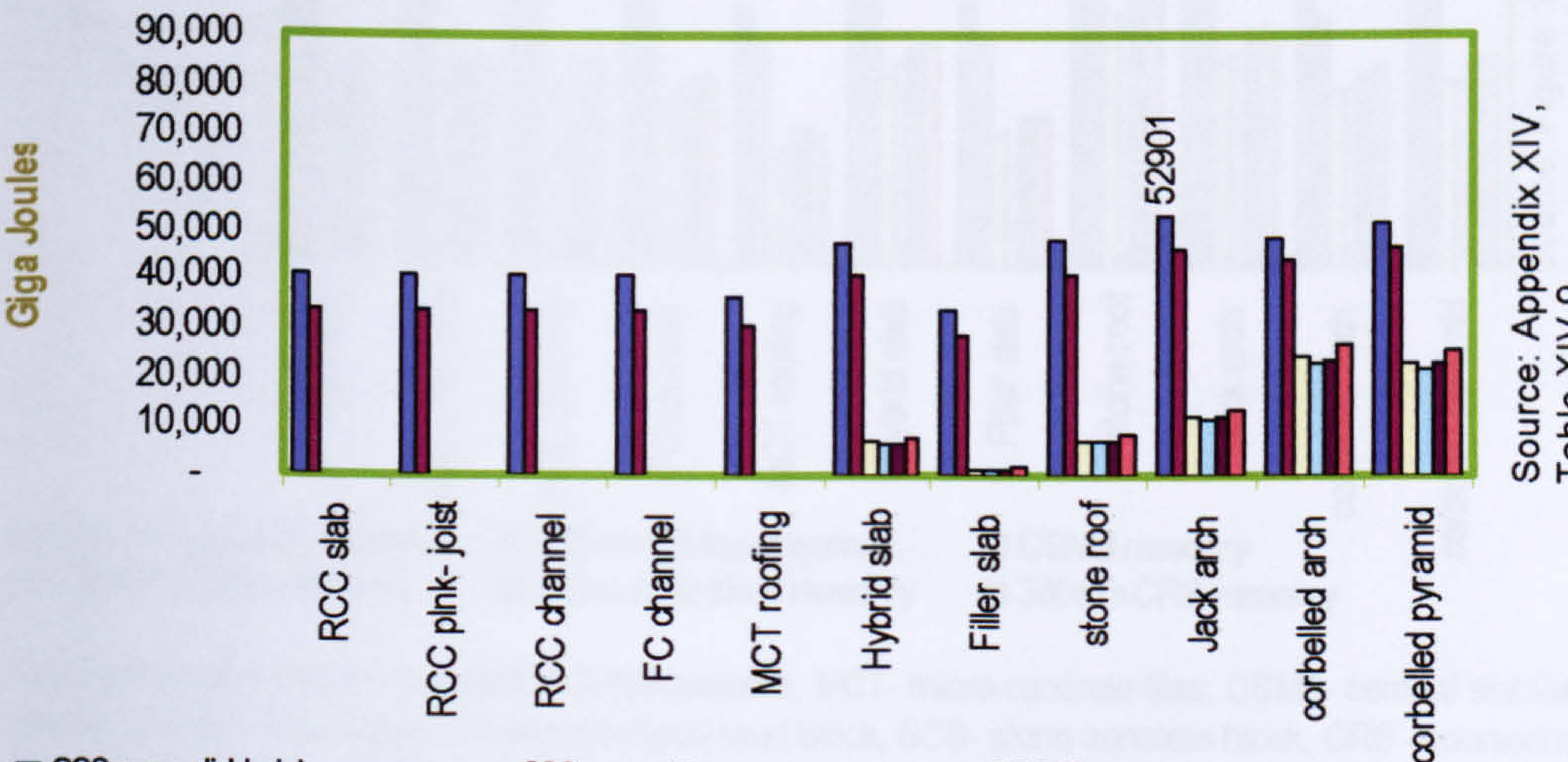


RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

Table 10.8 The two combinations of walling and roofing systems with maximum and minimum embodied renewable energy.

	Embodied energy in Giga Joules	Walling systems	Roofing systems
Maximum	14,648	380 mm coursed rubble stone masonry	Filler slab
Minimum	1,203	150 mm interlocking cement stabilised mud block masonry	Corbelled brick arch

Figure 10-9 The embodied energy (owing to rice husk burning) of 1068 classrooms using 66 walling and roofing combinations.



RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

Table 10.9 The two combinations of walling and roofing systems with maximum and minimum embodied energy owing to rice husk burning.

	Embodied energy in Giga Joules	Walling systems	Roofing systems
Maximum	52,901	230 mm solid brick wall	Jack arch on pre-cast reinforced cement concrete joists.
Minimum	0	*	*

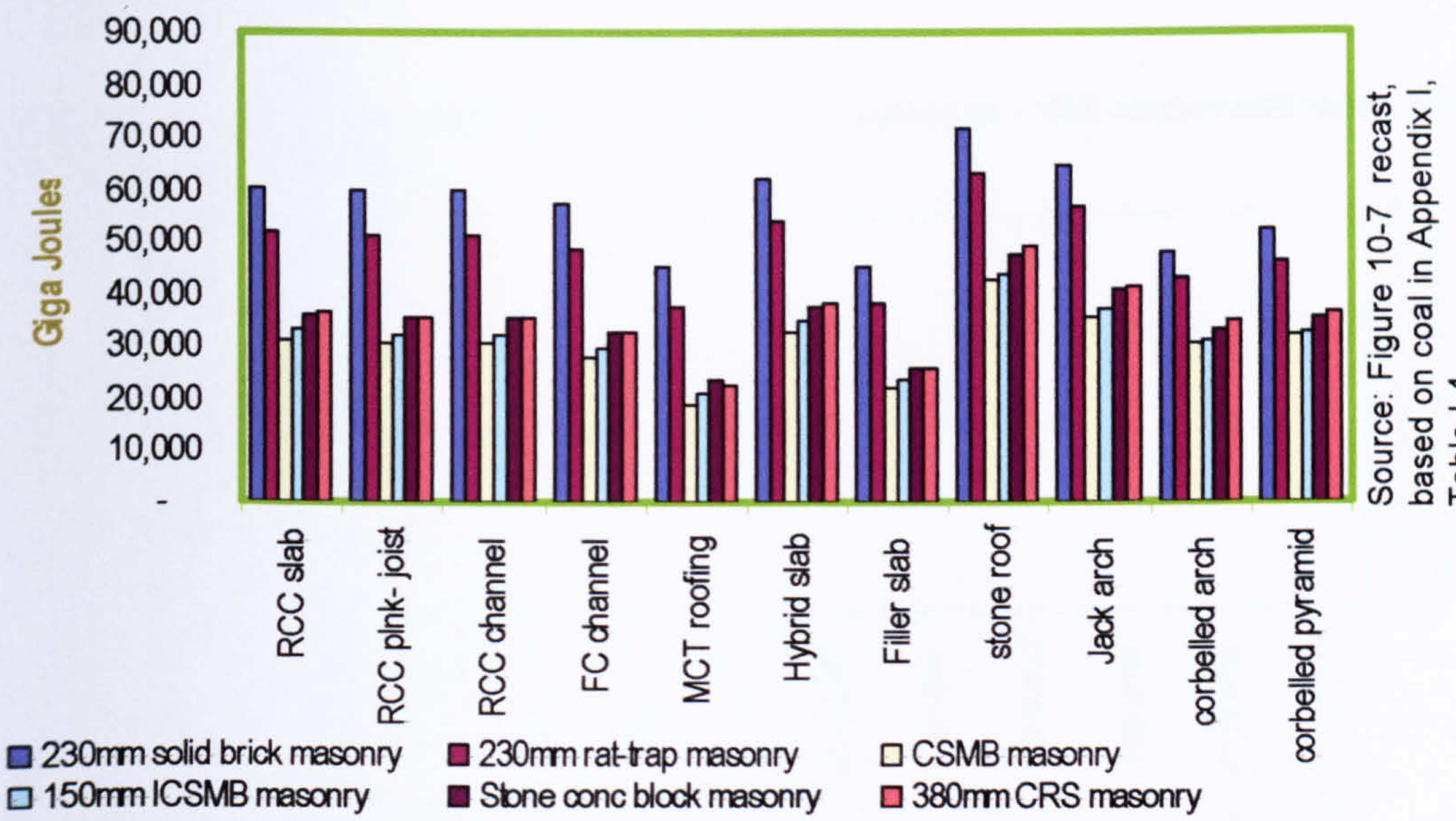
* The technologies that did not use rice husk as fuel had zero embodied waste energy.

Figure 10-7 to Figure 10-9 show that the construction technologies adopted in Ranga Reddy were highly non-renewable energy intensive. The embodied waste energy is visible only in the brick intensive systems. Therefore, in the context of Ranga Reddy, brick intensive systems were environment friendly, especially the combination with corbelled brick arch roofing and rat-trap bonded brick masonry.

BRICK PRODUCED BY USING COAL AS FUEL

All the data on embodied energy have been recalculated by assuming that the brick production is coal-based. Accordingly, the graphs in the Figure 10-7 to Figure 10-9 have also been recast and presented in Figure 10-10 to Figure 10-12, which show that the best walling options in Ranga Reddy are the most detrimental to the environment in other contexts.

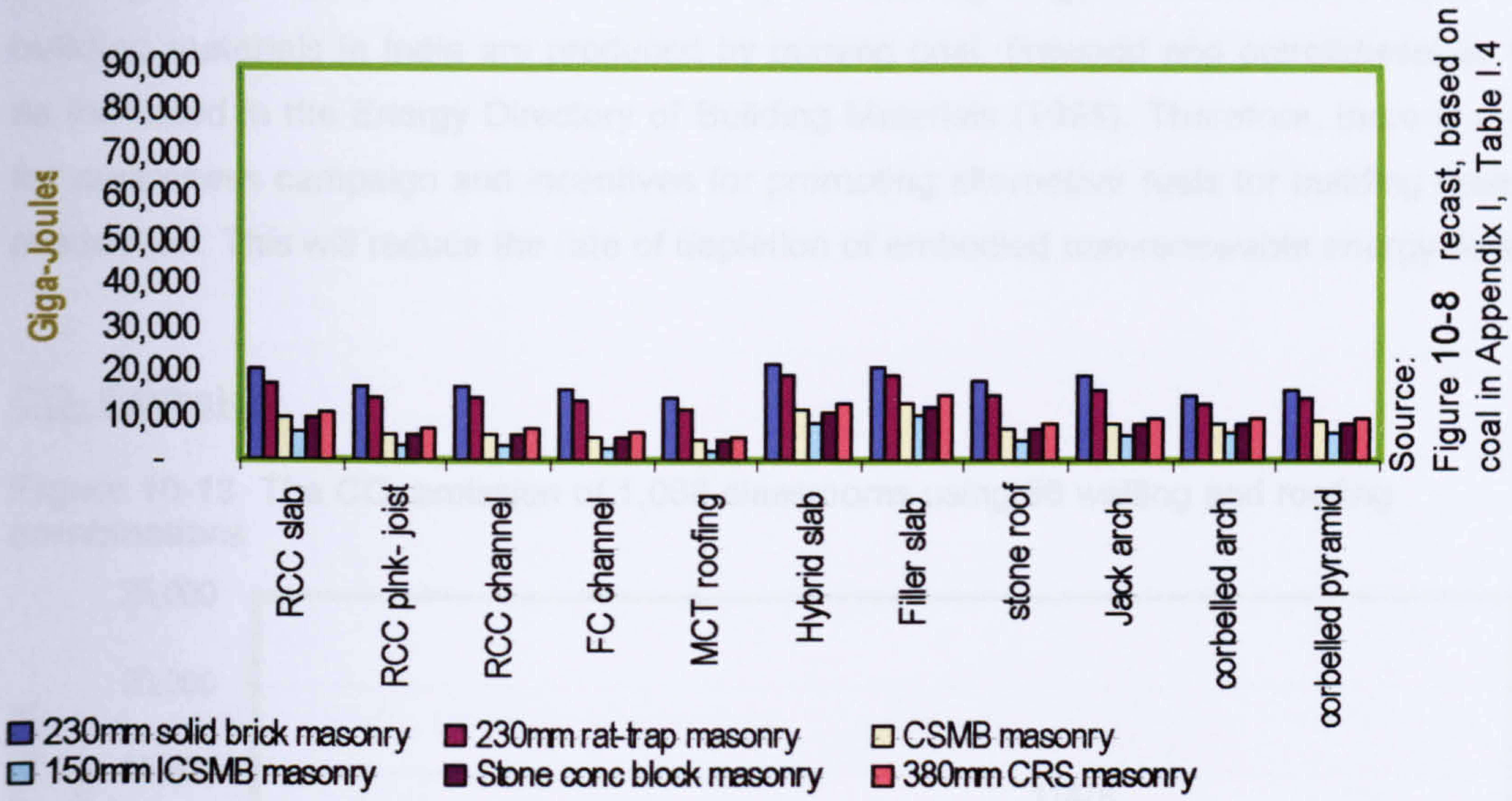
Figure 10-10 The embodied non-renewable energy of 1,068 classrooms using 66 walling and roofing combinations.



RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB –interlocking cement stabilised mud block, SCB- stone concrete block, CRS –coursed rubble stone

The above figure shows that solid brick and rat-trap bonded brick walls have very high embodied non-renewable energy. The most energy efficient combination is the cement stabilised mud block masonry wall with micro-concrete tile roof. The next best option is the same wall with filler slab.

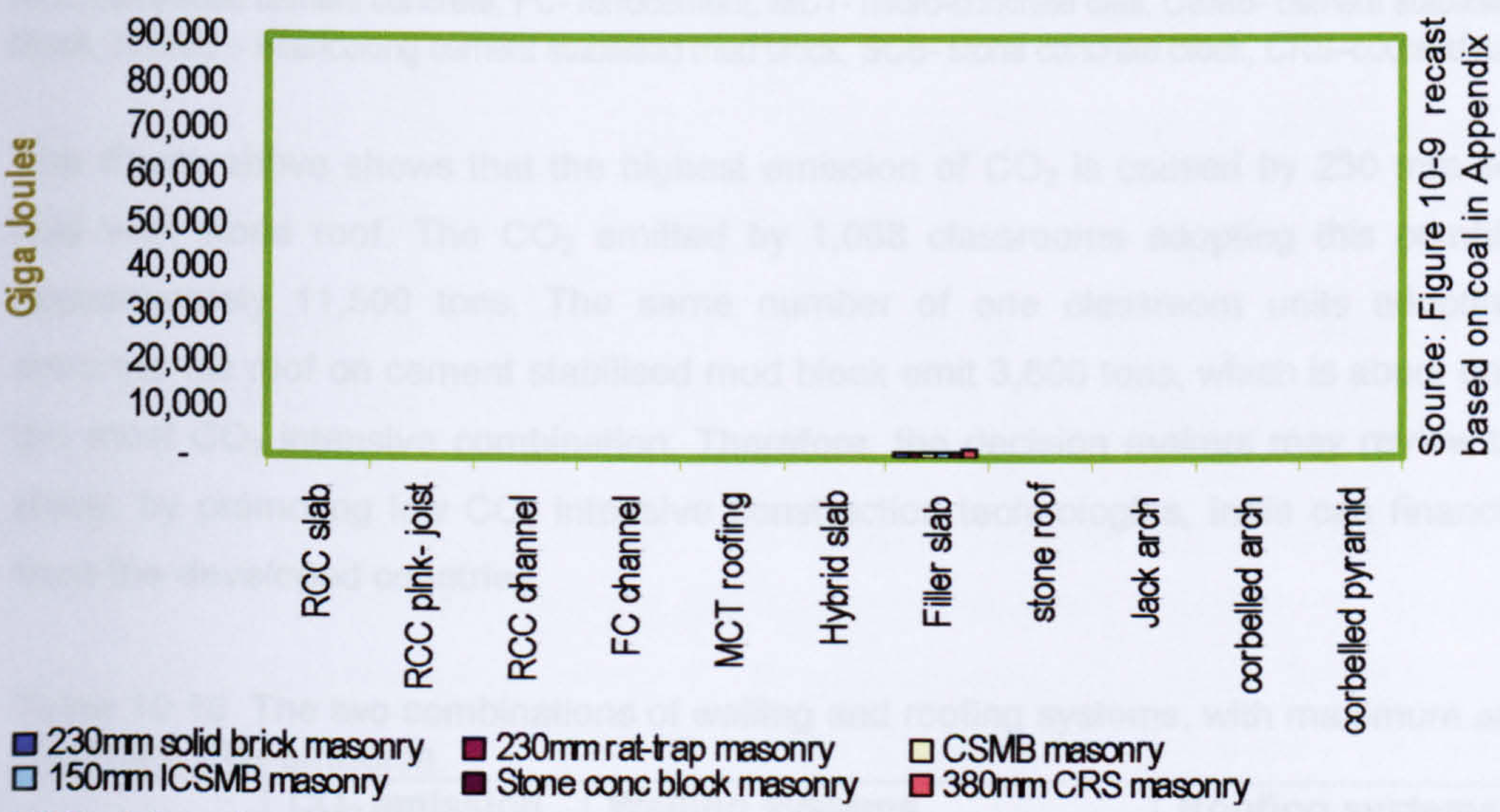
Figure 10-11 The embodied renewable energy of 1,068 classrooms using 66 walling and roofing combinations.



RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

The roofs in combination with the brick intensive walls show high embodied renewable energy. The roofing systems in combination with interlocking cement stabilised mud block show low embodied renewable energy. Cement stabilised mud block and stone concrete block masonry walls have low embodied renewable energy compared to that of the brick intensive systems.

Figure 10-12 The embodied energy (agriculture waste) of 1,068 classrooms using 66 walling-roofing combinations.

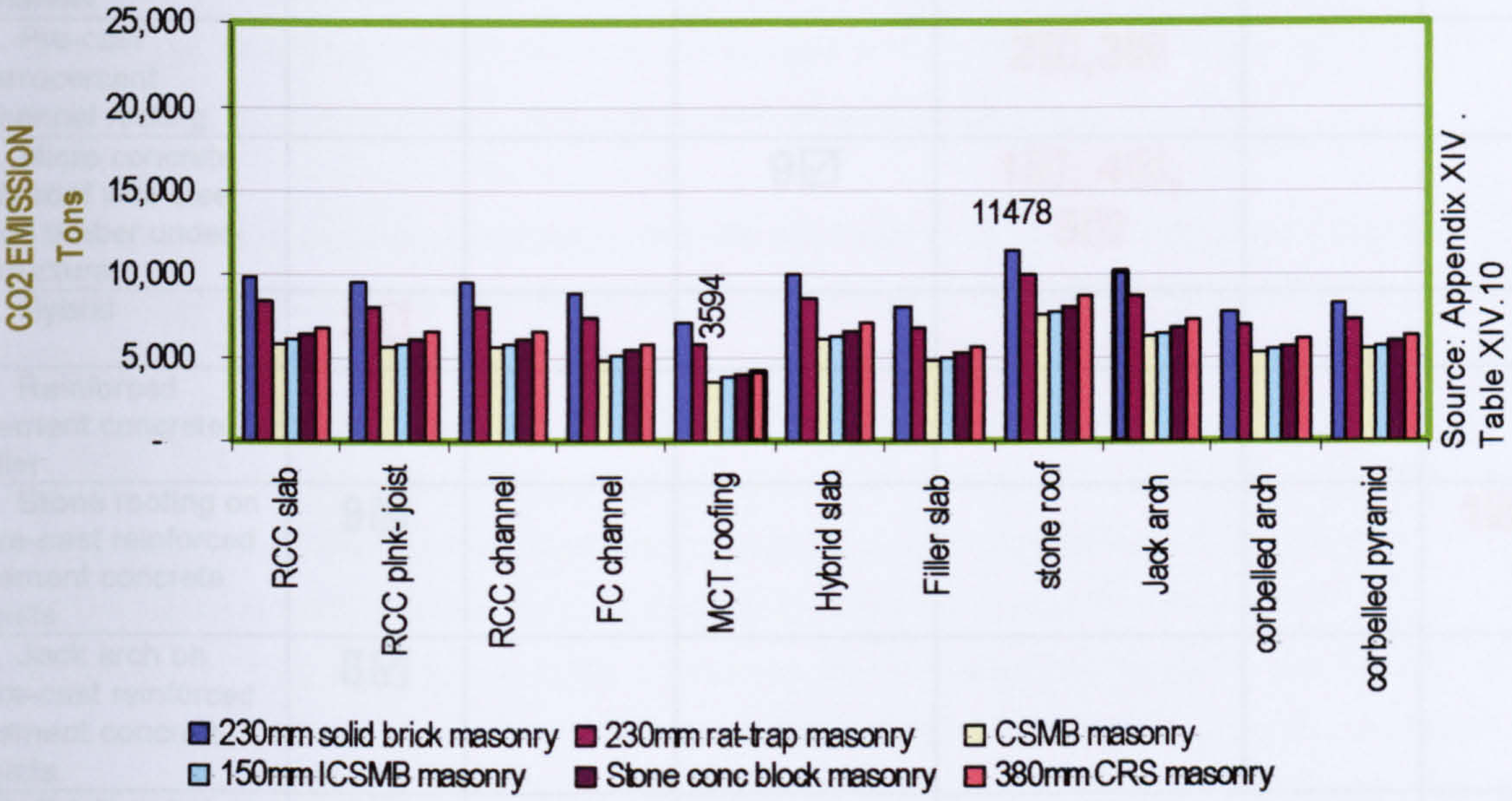


RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

Figure 10-12 shows that the use of rise husk or similar agriculture waste in the building materials production in India is virtually non-existent. The small amount of waste energy is observed in filler slab which uses clay tiles as filler materials. It may be noted that wood shavings, rice husk, etc., are used for clay tile burning in general. However, most of the building materials in India are produced by burning coal, firewood and petrol/diesel as fuels as indicated in the Energy Directory of Building Materials (1995). Therefore, there is a need for awareness campaign and incentives for promoting alternative fuels for building materials production. This will reduce the rate of depletion of embodied non-renewable energy sources.

CO_2 Emission

Figure 10-13 The CO_2 emission of 1,068 classrooms using 66 walling and roofing combinations



RCC-reinforced cement concrete, FC- ferrocement, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS–coursed rubble stone

The figure above shows that the highest emission of CO_2 is caused by 230 mm solid brick wall with stone roof. The CO_2 emitted by 1,068 classrooms adopting this combination is approximately 11,500 tons. The same number of one classroom units adopting micro-concrete tile roof on cement stabilised mud block emit 3,600 tons, which is about one third of the most CO_2 intensive combination. Therefore, the decision makers may review this issue since, by promoting low CO_2 intensive construction technologies, India can financially gain from the developed countries.

Table 10.10 The two combinations of walling and roofing systems, with maximum and minimum CO_2 emission.

	CO_2 emission in tons	Walling systems	Roofing systems
Maximum	11,500	230 mm solid brick wall	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	3,600	Cement stabilised mud block	Micro concrete tile roofing

10.4. SUMMARY CHART

Table 10.11 Summary chart (☑ and ☒ indicate the most and least favourable option).

WALLING / ROOFING	230 mm solid brick wall	230 mm rat trap bonded brick wall	230mm cement stabilised mud block wall	150 mm interlocking cement stabilised mud block wall	Stone concrete block wall	380 mm coursed rubble stone masonry wall
1. Reinforced cement concrete in-situ						
2. Reinforced cement concrete plank and joist						
3. Reinforced cement concrete channel						
4. Pre-cast ferrocement channel roofing				2☒,3☒		
5. Micro concrete tile roof with steel and timber under-structure			9☑	1☑, 4☒, 5☒		
6. Hybrid	2☑					
7. Reinforced cement concrete filler						7☒
8. Stone roofing on pre-cast reinforced cement concrete joists	9☒					1☒, 5☑, 6☒
9. Jack arch on pre-cast reinforced cement concrete joists.	8☑					
10. Brick corbel arch	4☑	6☑		7☑		3☑
11. Brick pyramid						

Legends : unit cost (1), retention (2), skilled (3), semiskilled (4), unskilled (5), non-renewable energy (6), renewable energy (7), waste (8) and CO_2 emission (9).
Based on the Figure 10-2 to Figure 10-9 and Figure 10-13.

Table 10.11 shows the most favourable and the least favourable combinations of walling and roofing systems. This chart gives an opportunity to the decision makers to look at the summary of socio-economic and environmental impacts of the walling and roofing combinations in a particular context. The numbers attached with each tick or cross mark denotes the parameter number, viz. unit cost (1), retention (2), skilled (3), semi-skilled (4), unskilled (5), non-renewable energy (6), renewable energy (7), waste (8) and CO_2 emission (9). The decision maker will ideally consider those options where only tick marks exist. However, there are combinations in Table 10.11, where tick and cross both exist, thus reducing the ease of decision making. While this chapter provides a view of the scale of impacts under the nine socio-economic and environmental parameters, it does not lead to the best combination of walling and roofing technologies in a particular context, which will be carried out in chapter 12 on scoring.

CHAPTER 11 LIFE CYCLE ANALYSIS

11.1 BACKGROUND

According to Cole and Sterner (2000), discussed in chapter 2, the life cycle cost analysis is a data intensive process and the final outcome is highly dependent on the accessibility, quality and accuracy of input data. Ashworth (1993) also states that there is a lack of appropriate, relevant and reliable historical cost information and data. However, Ashworth and Hogg (2000) observed that there is some evidence from practice that life cycle costing is being more extensively used, particularly so in the case of major works projects, among clients who carry out an extensive amount of construction work and among those who are well informed of the consequences of design decisions on overall project costs.

The fundamental problem associated with the application of life cycle costing in practice is the requirement to be able to forecast a long way ahead in time (Ashworth, 1993). The main difficulties are similar to those of weather forecasting and other activities that attempt to predict a future event. All forecasts are fraught with some sorts of confidence credibility, but this does not mean that they should not be attempted. Weather forecasting, for example, is based on huge databases that have been systematically collected over time. Even so, it is still unable to provide reliable forecast weather pattern for even a few days ahead. Despite the relatively long history, life cycle costing is yet to gain importance in the domain of decision making in contemporary building design, owing to a general lack of motivation, methodological problem and access to reliable data (Cole and Sterner, 2000). Cole and Rousseau (1992) have analysed the methodological problems of calculating life cycle embodied energy of building materials (chapter 2).

The most effective use of life cycle costing is at the design-decision making stage. Life cycle costing can be used to evaluate the various options in the design in order to assess their economic impact throughout the project's life. In selecting the design from a number of feasible options, the one with the lowest life cycle cost will usually be the first choice, provided that other performance measures or criteria have been met.

It may be noted that the widely used term "life cycle analysis", mostly focuses on the costing only and does not include aspects such as embodied energy, emission of CO_2, etc. Since this dissertation attempts to develop an impact assessment tool by considering nine socio-economic and environmental parameters, from here onwards it will be termed as life cycle impact assessment.

11.2 LIFE CYCLE IMPACT ASSESSMENT IN THE CONTEXT OF RURAL INDIA

In view of the above discussions, it may be suggested that the professionals and the researchers need to focus on acquiring reliable databases on life cycle impact assessment that currently suffers from the problem of inadequate historical data. Attempting to predict life cycle implications without it will be like having an exact solution to an approximate problem. In such a situation, the Andhra Pradesh Primary Education Project database may be adopted as a reasonably good starting point in the Indian context. It may be re-iterated that the Andhra Pradesh Primary Education Project buildings were constructed under uniform supervision by a group of trained engineers and architects. These buildings are in one geo-climatic setting and are being used by the people belonging to one ethnic group. Under such circumstances, it may be reasonable to assume that the rate of their ageing will generate reliable historical data on life cycle impact assessment.

The first evaluation report (DFID, 1999) on the physical conditions of Andhra Pradesh Primary Education Project buildings and data on the subsequent intervention (by the author) in 1999-2000 for these buildings have been used as the baseline data on life cycle impact assessment of different construction techniques. A rapid evaluation of the physical condition of these school buildings was conducted by the author between 18th and 25th December 2003. As far as possible, the sites were visited during the school hours to interact with the teachers and the pupils. The school teachers informed that there was no need for further preventive or corrective interventions after the DFID funded project in 1999-2000. Almost all the schools were in acceptable condition though some, where the housekeeping was good, were better than others. The rapid evaluation tends to support the predictions on routine preventive maintenance, which was assumed to be after every four years in chapter 6. The different roof waterproofing treatments were in good condition. However, the assumption of ten years as the frequency of intervention for the roof treatment could not be ascertained since the inspection (2003) was only about three and half years after the intervention in 1999-2000. Similarly, a rapid survey may be conducted in 2008 to make the database for life cycle analysis more reliable.

The database of Andhra Pradesh Primary Education Project on life cycle impact assessment of the walling and roofing technologies appears to have good potential for applications in other contexts. By adopting the impact assessment and evaluation method developed in chapter 7, the database of Andhra Pradesh Primary Education Project may be used to study the life cycle impacts of the different combinations of walls and roofs in other contexts as well. This will be similar to the last chapter on impact assessment, in which the District Primary Education Project has been adopted for demonstrating the impacts. However, the data of levels 1, 2 and 3 have to be modified depending upon the local conditions.

It is important to note that there were some indications of sustainability of the community-assisted repair of the school buildings in 1999-2000. According to the education department's trend, most of the teachers were within the adjacent districts in December, 2003 and hence, the institutional memory on the methods of carrying out building maintenance still existed. The school teachers and the villagers showed their enthusiasm when they saw that the survey team was back in the villages and were taking notes on the performance of the buildings repaired by them in 1999-2000. While it costs about £ 2000 per survey, repeating it at the frequency of four years will enrich the database for the architects and engineers and also it will have positive impact on the community's confidence in the cost effective construction technologies.

Thus the trend setting for life cycle impact assessment in India's rural construction sector may start with a simple method developed in chapter 7 to make it acceptable to the state engineering departments and the key decision makers at union Government level. Once people start using the impact assessment tool and become used to it, more sophisticated methods may evolve over time.

11.3 THE SCOPE OF LIFE CYCLE IMPACT ASSESSMENT IN THE PRESENT CONTEXT

The following have been assumed for carrying out life cycle impacts assessment of different combinations of walling and roofing systems applied to 1,068 classroom units of internal dimensions 5.5 metres x 5.5 metres.

- The life cycle analysis in this section will focus on the roof and wall only, which constitute about 58% (chapter 5) of the total cost of a rural primary school. All other assumptions are the same as in the last chapter.

- This dissertation excludes operating energy costs of the primary schools from the life cycle analysis. It may be noted that the operating energy requirements in the rural primary schools of India are negligible compared to that of the developed countries, which spends a lot of money on heating and cooling. The evaluation of District Primary Education Programme revealed that most of the primary schools in the 18 states of India do not have access to electricity (Das et al, 2004). While some primary schools close to the grids have electrical connection, many others do not have access to electricity. Under such circumstances impacts of operating energy has not been considered in the life cycle impact assessment.

- Defect analysis of the Andhra Pradesh Primary Education Project buildings in chapter 6 has shown that the defects in construction technologies can be attributed to faulty design and detailing, inadequate standard of workmanship and the use of poor quality construction materials. Of these, the first and the last factors may be avoided to a great extent by using the Andhra Pradesh Primary Education Project database as a check list, and also by conducting capacity building programmes for the architects, engineers and supervisors. The defects owing to inappropriate workmanship may also be reduced to an extent by training the masons. However, all these can not be reduced to zero. Also, there is no rational basis for predicting the chances of occurrences of the three categories of mistakes in a construction project. Therefore, the following have been assumed;

  - The design mistakes will not occur.
  - Materials will be according to the specifications of the relevant Bureau of Indian Standards.
  - Masonry skill will be adequate.

Let us now analyse the impacts of the defects found in the different walling and roofing systems adopted in Andhra Pradesh Primary Education Project after four years of construction (Table 11.1). The main objective of this section is to evolve a rational method for life cycle impact analysis of the following roofing and walling systems.

Table 11.1 The walling and roofing systems considered for life cycle impact assessment.

	Roofing systems		Masonry walling systems
1	Reinforced cement concrete	1	230 mm solid brick wall
2	Reinforced cement concrete channel	2	230 mm Rat-Trap Bonded masonry
3	Reinforced cement concrete plank and Joist	3	Cement stabilised mud block 5%
4	Ferrocement channel	4	Interlocking Cement stabilised mud block 10%
5	Filler slab	5	Stone concrete block
6	Hybrid slab	6	Coursed rubble stone
7	Micro concrete tiles		
8	Stone roofing		
9	Jack -arch roofing		
10	Corbelled arch roof		
11	Corbelled brick pyramid		

11.4 LIFE CYCLE IMPACT ASSESSMENT: ROOFING AND WALLING SYSTEMS ADOPTED IN ANDHRA PRADESH PRIMARY EDUCATION PROJECT

The evaluation team's recommendations on the Andhra Pradesh Primary Education Project buildings in November, 1998 were reviewed in January 2000 by carrying out a fresh investigation involving the Government engineers. This was done to develop capacities of the Government engineers regarding defect analysis and condition assessment of the school buildings. The teachers and the community were also involved in the process of defect identification and mapping because they were aware of the defects in great detail. For example, they knew if there was a damp patch on the ceiling immediately after the rains, which disappears in about two to three days. This type of defect may be difficult for the engineers to detect while carrying out the survey. Let us now analyse the defects of 11 roofing systems adopted in Andhra Pradesh Primary Education Project. This section analyses the defects in roofing systems and examines the validity of the assumptions on frequency of preventive and corrective measures assumed in chapter 6. The next section will carry out a similar exercise on the 6 walling technologies adopted in Andhra Pradesh Primary Education Project.

11.4.1. Defect Analysis of the Roofs

REINFORCED CEMENT CONCRETE CHANNEL AND REINFORCED CEMENT CONCRETE PLANK AND JOIST

The condition survey of the Andhra Pradesh Primary Education Project buildings in 1999-2000 revealed that pre-cast reinforced cement concrete channel roofing and plank and joist roofing had similar types of defects. A primary school, according to Bureau of Indian standards on spatial requirements and the visibility of the blackboard, should preferably have a room-width of 5.5 metres. The economic structural span of pre-cast roofing elements such as plank and joists and channels is between 3.65 and 4.25 metres for the residential (200 kilogram per square metre) and office type (300 kilogram per square metre) of live load. Therefore, a span of 5.5 metres of pre-cast plank and joist or channel units will make them expensive and heavy to lift manually. It may be noted that procurement of mechanical lifting device in the rural areas of India is difficult and expensive. Therefore, the maximum self-weight of the component was kept within 200 kilograms, which could be lifted manually by a group of eight people. While doing this, the reduced length of plank and joist and channel units needed an intermediate support and hence, a reinforced cement concrete beam had to be introduced at the centre of the room and across the width. The plan and section and the defects of these two types of roofing systems are shown in Appendix VIII.

As mentioned in section 6.5.4 (chapter 6), the pre-cast roofs had developed cracks on the supporting beam. Two toe walls with a coping stone on top was provided as corrective action, which allows the thermal movements and protects the roof from rain water seepage. The cost of such rectification has been added to the original cost of the roofing system. Therefore, the life cycle analysis will assume that roof treatment of 1:3 cement-sand mortar with waterproofing compound will be re-laid after every 10 years and white washing after every 4 years. It may be noted that the Government engineers in Andhra Pradesh, based on their experience, suggested that the frequency of corrective maintenance of the roof waterproofing should be 10 years. While 100% replacement of the treatment will not be necessary, this will take care of the expenditure on extra labour charges for the removal of the damaged portion.

Table 11.2 The frequencies of corrective and preventive maintenance of reinforced cement concrete (RCC) slab, plank and joist, and channel roofing.

Roofing systems	Reinforced cement concrete slab* Reinforced cement concrete plank and joist Reinforced cement concrete channel
Corrective maintenance @ 10 years	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
Preventive maintenance @ 4 years	Lime washing - three coats

* According to Central Public Works Department Specifications (CPWD, 2002)

FERROCEMENT CHANNEL

Several types of ferrocement channel sections are used in India, out of which the semicircular one is popular owing to the ease of de-moulding and erection. However, semicircular channel roofing has been reported to have seepage problem through the joints between two adjacent units, which usually develop minor cracks. When two matured ferrocement channels are placed side by side and the joints are sealed with in-situ sand-cement mortar, the latter does not usually develop a density matching the neighbouring channels. Apart from that the shrinkage in fresh joints tends to develop a minor separation from the channel sides. In 1996, the ferrocement channel roofs had developed minor cracks at joints even before the buildings were handed over to the Government. An impervious layer of bituminous felt was laid on the entire roof to make it waterproof.

The classrooms in Ranga Reddy district were oriented North-South for adequate ventilation. The ferrocement channels in the classroom roof were spanned in the North-South direction thus exposing the longer sides to the morning and afternoon solar radiations. During the field inspection (2000), it was noticed that the waterproofing layer had developed cracks parallel to the section of the channel facing West. However, the roof did not have any seepage problem since the cracks were not through the entire depth of waterproofing. The expansion and contraction of the channels were monitored for three weeks and it was noticed that the maximum difference in movements between day and night was four to five mm, which could have been the cause of partial damage in the waterproofing. Polymer-cement –screened sand (1:1:2) paint was applied on the channel in three coats. The roofing channel facing East was in good condition.

Apart from this there was no sign of structural problem in the ferrocement roofing. As discussed in chapter 6 (section 6.5.4), it may be reasonable to consider the corrective repair of applying polymer-based paint after every ten years with the present state of technology till a better one is developed. The following tables show the life cycle implications of ferrocement channel roofing.

Table 11.3 The frequencies of corrective and preventive maintenance of ferrocement channel roofing.

Roofing system	Ferrocement channel
Corrective maintenance @ 10 years	Polymer-cement –sand (1:1:2) - three coats
Preventive maintenance @ 4 years	Three coats of lime wash in ceiling

MICRO CONCRETE TILES

Micro concrete tile roofing was adopted in three buildings under Andhra Pradesh Primary Education Project and their performance was acceptable. The under-structure of the micro concrete tile roofing was painted with oil bound paint. In life cycle analysis, it has been assumed that the under-structure will be painted after every 4 years. Based on the average number of damaged tiles in Repair and Upgrading programme, it has been assumed that 5% tiles will be replaced after every ten years.

Table 11.4 The frequencies of corrective and preventive maintenance of micro concrete tile roofing on steel and timber under-structure

Roofing system	Micro concrete tile roofing on steel and timber under-structure
Corrective maintenance @ 10 years	Replacement of 5% tiles owing to breakages
Preventive maintenance @ 4 years	Painting of understructure with two coats of ready made mixed enamel paint

HYBRID SLAB

Hybrid slab consists of brick panels tightly fitted within the boundary of reinforced cement concrete ribs (Appendix-IV). The Government engineers of Andhra Pradesh in 1996 argued that there would be periodic differential movements between the brick panels and the ribs that will lead to seepage of rain water. Thermal movement between the ribs and brick panels was probably not possible owing to the high level of compressive stress in the brick panels. The field inspection in 2000 suggested that there was no crack at the junction between the brick panels and the reinforced concrete ribs, neither there was any water seepage from their junctions.

However, minor water seepage was observed at places owing to incorrect grading plaster, which had resulted in patches of water logging at a few locations. It is important to note that, in 1996, the village of Muduchinthalapally did not have a good roof shuttering contractor. Lack of skill may therefore, be attributed to the minor dampness. Capacity building will largely eliminate this problem. Therefore, relaying of waterproofing after every ten years (as with reinforced cement concrete slab) may be adopted for hybrid slab. The ribs in hybrid are 900 mm centre to centre and have a width 175 mm. Therefore, the total area of the ribs is 38.89% of the ceiling area, which is painted with lime. The following is the life cycle interventions of hybrid slabs.

Table 11.5 The frequencies of corrective and preventive maintenance of hybrid slab roofing.

Roofing system	Hybrid slab
Corrective maintenance @ 10 years	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
Preventive maintenance @ 4 years	Lime washing - three coats in ceiling

FILLER SLABS

Pitched filler slabs were used in Andhra Pradesh Primary Education Project and most of them performed well against rainwater. Five out of six buildings, having a filler slab, did not develop any major problem, except minor water seepage at places wherever, the roofs were flat on top, e.g., on corridors separating two main blocks of classrooms (Appendix-VIII, Figure VIII.10).

It is important to note that a folded filler slab is more economic than a flat slab owing to its reduced structural spans and hence, bending moments. The added advantage of folding the slab was easy drainage of rainwater. Structurally, filler slab is very similar to solid reinforced cement concrete slab and hence, the roof treatment of the latter was adopted in all five buildings having this roof. Therefore, in life cycle analysis, the same roof treatment has been assumed to be re-laid after every ten years. The following tables show the life cycle implications of folded filler slab roofing.

Table 11.6 The frequencies of corrective and preventive maintenance of filler slab roofing.

Roofing system	Filler slab with clay tile as filler material
Corrective maintenance @ 10 years	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
Preventive maintenance @ 4 years	Lime washing - three coats in ceiling

<u>**STONE ROOFING**</u>

Sloping and flat stone roofing systems were adopted in Andhra Pradesh Primary Education Project. Like the folded filler slabs, sloping stone roofs did not have major problem of water seepage. The sloping stone roofs were created by constructing a masonry arch in the centre of the room by dividing the space into two bays (Figure VIII.17, Appendix VIII). This had reduced the spans of the pre-cast joists to less than 3 metres. The rest of the roofing system was the same as plank and joist or reinforced cement concrete channel.

The flat stone roofs were similar to plank and joist roofing in which a central beam in the classroom was introduced to reduce the spans of the pre-cast reinforced joists. It is important to note that the stone roofs did not develop any crack along the length of the supporting reinforced cement concrete beam as in Chinnamangalaram. This may be owing to the fact that stone planks have a lower coefficient of thermal expansion than plank and joist or reinforced cement concrete channel units. Brickbat coba as a roof treatment might have acted as an adequate thermal insulator to the pre-cast reinforced cement concrete joist.

It may be noted that brickbat coba as a roof treatment is the most expensive and energy intensive of all the systems adopted in Ranga Reddy district. In Andhra Pradesh Primary Education Project, roofing stone was cheap and energy efficient. However, the use of brickbat coba as a roof treatment made it expensive, and energy and emission (CO_2) intensive. An alternative low cost and energy efficient roof treatment would have made stone roof one of the most acceptable solutions in Andhra Pradesh Primary Education Project.

Based on the Panchayati Raj Engineers' experience of replacing brickbat coba as waterproofing treatment after every 10 to 15 years, it has been assumed to be re-laid after every 10 years. The Stone roof joists are 900 mm centre to centre and cover 50% of the ceiling area, which is painted with lime. The following tables show the life cycle implications of stone roofing.

Table 11.7 The frequencies of corrective and preventive maintenance of stone slab roofing.

Roofing system	Stone slabs on pre-cast reinforced cement concrete joists
Corrective maintenance @ 10 years	Brickbat Coba - 1:4 cement mortar and brick bats
Preventive maintenance @ 4 years	Lime washing - three coats in ceiling

JACK-ARCH ROOFING

It is important to note that the jack-arch performed well in spite of the fact that they were also supported at the centre by reinforced cement concrete beam as in Chinnamanagalaram. The main cause of better performance of jack-arch roof could be attributed to the low coefficient of linear expansion of brick compared to that of reinforced cement concrete planks and joists or channels. Minor water seepage problem in the brick arch was noticed at Puppalguda, which could have been owing to faulty workmanship at a few spots. It may be noted that the specifications of the waterproofing on jack-arch roof is similar to that of reinforced cement concrete slab. Therefore, relaying 1:3 cement mortar with 0.2% waterproofing compound after every ten years will be considered in the life cycle analysis of jack-arch roofing. The jack arch roof joists are placed at 1200 mm centre to centre and covers 37.50% of the ceiling area, which is painted with lime. The following tables show the life cycle implications of Jack-arch roofing.

Table 11.8 The frequencies of corrective and preventive maintenance of jack-arch roofing.

Roofing system	Jack-arch on pre-cast reinforced cement concrete joists
Corrective maintenance @ 10 years	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
Preventive maintenance @ 4 years	Lime washing - three coats

CORBELLED BRICK PYRAMID AND CORBELLED ARCH ROOF

These two types of roofing systems are based on corbelling principles and did not require any scaffolding or shuttering since the masons can sit on the corbelled brick courses laid on the previous day and make two new courses of corbelling.

A significant amount of essential repair had to be done in the corbelled brick pyramid at Majeedpur. The cement coat as a waterproofing on 1:4 cement sand plaster developed cracks owing to inadequate water curing. It may be noted that there was too much evaporation loss since the construction took place in summer. Apart from that, tendency of the contractor to use a mix richer than specified also led to thermal cracks on the plaster.

When the school building project started at Majeedpur, the modalities of the contract and specifications were not finalised since rat-trap bonded wall and corbelled brick pyramid did not exist in the standard schedule of rates under the Government of Andhra Pradesh. It was a completely new technology to the engineers as well as the villagers. The engineers' main doubt was about the structural stability of the pyramid. They had never seen any roof being constructed without reinforced cement concrete and shuttering. The most surprising thing to them was that the masons were working on the brick corbels that had been laid on the previous day. While the masons gained confidence in the technology after a few days of laying corbelled brick courses, the engineers did not. After initial apprehensions, the work was completed at an acceptable quality. Later, it was learnt that the contractor had used 1:4 cement sand mortar out of fear, whereas it should have been 1:6 cement mortar according to the specifications. He thought that more cement will prevent the structure from falling down. Similarly, the contractor had used a richer mix (1:3 instead of 1:4) in waterproof plaster on the pyramid. It may be noted that cement was supplied by the Government engineering department according to the actual consumption at site. Therefore, the contractor was not financially affected by increasing the quantity of cement. He feared that he would be blacklisted for any eventuality. The Government engineer responsible for this project was aware of this but did not share it with DFID consultants since he was also unsure about the structural safety of pyramid.

The same contractor was appointed at Jaggamduga, where the same technologies were adopted. This was the second building project in Andhra Pradesh Primary Education Project and the contractor did the same thing by increasing cement in the pyramid. All these could not be detected until the buildings were completed and bills of materials settled.

Corbelled brick pyramids were used in Turkapally village, on an octagonal plan-form. The contractor of this building could not follow the trend of Majeedpur since by then the DFID consultant was aware of the mischief and vigilance at site was stepped up. It may be noted that the contractor at Turkapally was more confident about the structural stability of the pyramid after he had inspected those at Majeedpur and Jaggamguda.

Anatharam, where corbelled brick arch roof was adopted, was completed in June-July 1996. By then the agency could do an in depth survey of the waterproofing of the roof. The masons at Anatharam suggested that they would use 1:4 cement mortar as waterproof treatment. The freshly laid plastered roof surface was painted with cement slurry. This worked very well, which was evident from the inspection carried out in 2000, when the community informed that they had not experienced any leakage through the roof.

Therefore, it may be prudent to accept the waterproofing treatment of Anatharam for life cycle analysis of the pyramid roofs. The specification of the waterproofing at Anantharam is similar to the impervious coat on reinforced cement concrete slab. Therefore, as in the case of impervious coal, frequency of replacing waterproofing plaster on corbelled brick roof will be assumed as ten years. It may be noted that the undersides of the corbelled roofs were in good conditions except at a few locations there were minor defects were observed. These were re-pointed. The following table shows the life cycle implications of corbelled pyramid and arched roof.

Table 11.9 The frequencies of corrective and preventive maintenance of corbelled brick arch and corbelled brick pyramid roofing.

Roofing systems	Corbelled brick arch roofing Corbelled brick pyramid roofing
Corrective maintenance @ 10 years	Impervious coat with cement mortar (1:4) – 20 mm thick with 0.2% waterproofing
Preventive maintenance @ 4 years	5% of the ceiling area to be re-pointed with 1:3 cement sand mortar

SUMMARY OF DATABASE FOR THE LIFE CYCLE IMPACT ANALYSIS OF THE ROOFING SYSTEMS ADOPTED IN ANDHRA PRADESH PRIMARY EDUCATION PROJECT.

The different roofing systems adopted in Andhra Pradesh Primary Education Project have performed reasonably well without developing major problem over seven years (1996-2003). The structural stability, therefore, is not the issue as apprehended by the engineers of Panachayati Raj Engineering Department, Andhra Pradesh in 1995-96. The most frequently occurred defect in a roof had been waterproofing treatment. The evaluation of these buildings in November, 1998 indicated that the impervious coats on roofs did not perform as well as envisaged in 1995-96. However, the waterproofing treatments were not inappropriate. It has been explained that non-compliance with the specifications, inadequate workmanship, etc., were the causes leading to the problems. If one learns from the Ranga Reddy repair experience, the chances of occurrences of the defects may be low. It is apparent from the discussions that waterproofing is the most important element in life cycle analysis of different roofing systems apart from the factors like unit cost of construction and the degree of labour intensity. To observe the performance of these roof treatments, the existing systems have been considered in life cycle analysis.

The Panchayati Raj Engineering Department's documents indicated that the entire roof treatment is rarely damaged. They consider a replacement of roof treatment as a major repair, which usually takes place after between 10 and15 years. Under such major repair, only the damaged portions are chiselled out and fresh waterproofing is done on them. In this section, a frequency of 10 years has been adopted for the major repair and 100 percent replacement of the waterproofing has been considered to take care of the extra labour charges for chiselling out the damaged treatment and clearing off the debris. Following is the summary of database for life cycle analysis of roofing systems

Table 11.10: The specifications of the roof treatments applied at the time of construction and replaced after every ten years

	ROOFING SYSTEMS	SPECIFICATIONS OF THE DIFFERENT ROOF TREATMENTS
1	Reinforced cement concrete slab	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
2	Pre-cast reinforced cement concrete plank and joist	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
3	Reinforced cement concrete channel	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
4	Ferrocement channel	Polymer-cement –sand (1:1:2) - three coats
5	Micro concrete tile roofing	5% tiles will be replaced after every ten years
6	Hybrid slab	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
7	Folded filler slab	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
8	Stone roofing	Brickbat coba - 1:4 cement mortar and brick bats
9	Jack-arch roofing	Impervious coat with cement mortar (1:3) – 20 mm thick with 0.2% waterproofing
10	Corbelled brick arch roofing	Impervious coat with cement mortar (1:4) – 20 mm thick
11	Corbelled brick pyramid roofing	Impervious coat with cement mortar (1:4) – 20 mm thick

Source: Author

The routine preventive maintenance will be carried out by applying two coats of lime washing including cost and conveyance of all materials and labour charges taxes charges etc., after every four years on the soffit of the roof. Only in corbelled arch and pyramid roof 5% of the ceiling area has been assumed to be re-pointed with 1:3 cement sand mortar. For the micro concrete tile roofing, the under-structure will be painted with oil bound colour and for the hybrid, jack arch, stone roofing, etc., the pre-cast reinforced cement concrete joists will be painted with lime.

11.4.2. Defect Analysis of the Walling Systems

The performance of the different walling systems used in Andhra Pradesh Primary Education Project, have been explained in the chapter 6. In the repair works of the walls, 100% extra labour charge has been added for de-plastering, scraping, cleaning, etc. For all repair works, 50% extra material charge has been added for wastage and high transportation charges. The following is the defect analysis of the six different walling systems adopted in Andhra Pradesh Primary Education Project.

SOLID BRICK WALL

Solid brick wall of 230 mm thickness is constructed with wire-cut bricks and 1:6 cement sand mortar. This is the most widely used walling technology across the country. In Ranga Reddy district, the solid brick walls were plastered and painted with lime. The general complaint about this type of walling system was a few cases of erosion of bricks and plaster getting damaged in the lower part of the wall owing to exposure to sun, rain and wind. The field investigation of solid brick wall in 2000 under the Repair and Upgrading programme revealed that about 10-15% of the area of external plaster had very mild erosion. Some of the existing residential buildings of similar walling systems were examined along with the villagers, local masons and the Government engineers. The team came to a conclusion that about 20% of the plastered areas of solid brick wall should be repaired after every ten years. The following table shows the life cycle impacts of solid brick masonry wall.

Table 11.11 The frequencies of corrective and preventive maintenance of solid wall.

Walling system	Solid brick wall
Corrective maintenance @ 10 years	20% of the external surface to be re-plastered. The first coat in 1:5 cement-sand mortar (8 mm thick) and second coat in 1:3 cement-sand mortar (4 mm thick).
Preventive maintenance @ 4 years	Internal painting with three coats of lime wash

RAT-TRAP BONDED MASONRY

The rat-trap bonded wall did not develop any major problem, excepting that a few bricks in all the buildings were eroded owing to manufacturing defect. The brick field owners reported that they had noticed the problem of erosion and had also received complaints from the users. They had stopped the production for a while and then restarted after rectifying the manufacturing defects in bricks. Therefore, it was expected that the erosion problem will not occur in future. Therefore, the replacement of the eroded bricks has not been considered in life cycle analysis.

In one or two places, the pointing on rat-trap masonry was found loose. However, this was over a small area and only in two buildings. The average area of the defective pointing was less than 10% of wall surface. Under Andhra Pradesh Primary Education Project, a survey was conducted in 1994 to study the performance of rat trap wall and filler slab in Kerala, India. It revealed that the worst case of deterioration in rap trap was loose pointing of a maximum of 20-25% of the wall areas. Based on Kerala experience and the Repair and

Upgrading Programme of the school buildings in Ranga Reddy district, it has been assumed that a maximum of 30% of the wall area may need re-pointing after every ten years. The following table shows the life cycle impacts of rat-trap bonded masonry wall.

Table 11.12 The frequencies of corrective and preventive maintenance of rat trap wall.

Walling system	Rat trap wall
Corrective maintenance @ 10 years	30% of the external surfaces to be re-pointed with flush pointing to in 1:3 cement sand mortar.
Preventive maintenance @ 4 years	Internal painting with three coats of lime wash

Cement Stabilised Mud Block Masonry (5% Cement Stabilisation)

Erosion of stabilised mud block had been a common problem in Andhra Pradesh Primary Education Project. Considering the high level of quality control in block production, it may be reasonable to state that the problem of erosion was owing to some other reason. A rigorous inspection of the buildings revealed that stabilised mud blocks needed protection from rain. It is important to note that, while using stabilised mud block masonry in design, the architect has to protect the walls from rains as much as possible. For example in Kokapet, the verandah roofs on either side of the covered rooms were on the prevailing direction of wind in monsoon. Therefore, this building did not have a major erosion problem. In Gandipet, the building did not have such protections and as a result it had developed maximum erosion in the stabilised mud walls. The groove pointing enhanced the process of erosion by exposing more surface area to the rain and wind. During the Repair and Upgrading programme in 1999-2000, the grooves were filled-up and were converted to flush pointing. The recent inspection in 2003 showed that the flush joints have performed well in the last three and a half years.

One has to consider other aspects of using cement stabilised mud block as a walling material. It was noticed in a few schools that the children play a game in which they run around the building and while doing so they touch the wall continuously with their figures (chapter 6, Figure 6.12). This type of actions had broken the wall corners. A strip of plastering was applied to round off the sharp corners.

Stabilised mud block wall did not have a water repellent surface and hence, it absorbed some rain water. The portion of the walls having more exposure to rainwater than its sheltered areas showed higher level of erosion. The rate of erosion was high in unsheltered wall surfaces that were exposed to high wind during monsoon, which did not happen in the sheltered walls. Under such circumstances, it was felt necessary to protect the walls by applying stabilised mud plaster with 7% cement stabilisation on the unsheltered areas of the stabilised mud block walls. Its performance was found to be acceptable when these buildings were inspected in December, 2003. In Pondicherry, New Delhi and Bangalore, several buildings made of cement stabilised mud block walls were examined to have an idea on the performances of such walls against sun and rain. It was learnt that about 30% of the wall areas of the buildings were re-plastered with a frequency of about twelve years. Based on the study it has been assumed that 7% stabilised mud plaster will be applied after every ten years for the life cycle analysis of stabilised mud block masonry, The following table shows the life cycle implications of stabilised mud block masonry.

Table 11.13 The frequencies of corrective and preventive maintenance of cement stabilised mud block (5%) wall.

Walling system	Cement Stabilised Mud block (5%)
Corrective maintenance @ 10 years	30% of the external surfaces to be re-plastered with sponge finish 15 mm thick plaster in 1:4:8 mortar (cement, screened sand and mud).
Preventive maintenance @ 4 years	Internal painting with three coats of lime wash

INTERLOCKING CEMENT STABILISED MUD BLOCK MASONRY (10% CEMENT STABILISATION)

While stabilisation with 5% cement does not pose any strength problem in mud block masonry wall, it needs a water repellent plaster to make it endure for fifty years. Some technocrats believe that mud blocks with cement stabilisation higher than 5% will eliminate the erosion problem of stabilised mud block technology. By trial and error, they have arrived at 10% as an optimum percentage of cement stabilisation from the point of view of durability. To compensate for the increase in cost and embodied energy owing to high cement content, the wall thickness has been reduced to 150 mm. In addition to that, the blocks are made hollow and the joints are interlocking to facilitate mortar-less masonry. This type of blocks are called interlocking cement stabilised mud block (Appendix III).

Let us now examine the type of defects developed in this walling system. Higher percentage of cement and reduced thickness make these blocks thermally more sensitive than brick masonry. It has already been explained in chapter 6 that vertical cracks were noticed on the west-facing walls of two buildings oriented north-south. The East-facing wall did not develop any crack. The North and South facing walls were sheltered because of the two verandas and, hence, did not develop any crack. A discontinuity provided in the centre of the West-facing wall would have eliminated the problem of cracking owing to thermal movements. It will be reasonable to assume that the designer will not repeat this mistake and thus it can be excluded from the life cycle analysis.

The interlocking stabilised mud block had developed very minor surface deterioration. Under the Repair and Upgrading programme, water repellent paint made of polymer-cement was applied in three coats on the external surfaces. The external surfaces of this type of walls appeared much better than the cement stabilised mud block masonry. Interlocking block was a new walling material and hence, we were not aware of any existing building made of it. Therefore, there was no scope for examining the maintenance requirements of interlocking block masonry in other contexts. It may be noted that polymer-cement paint was applied on the external surfaces of interlocking block walls as a protective coat in 2000. An inspection in December, 2003 revealed that its condition was almost intact. Under such circumstances, the frequency of applying polymer-cement-sand as a protective coat on walls has been assumed to be after every ten years as with the other waterproofing treatments. Therefore, the strength of such assumption is low at present. However, it is expected that another revisiting the sites in 2008 will reveal more reliable data on this issue than at present.

Based on the areas of mild defects developed, it has been assumed that polymer-cement paint should be applied on 30% of the total external surfaces of interlocking cement stabilised mud block wall. The following table shows its life cycle implications of the corrective and preventive maintenance.

Table 11.14 The frequencies of corrective and preventive maintenance of interlocking cement stabilised mud block (10%) wall.

Walling system	Interlocking Cement Stabilised Mud block (10%)
Corrective maintenance @ 10 years	30% of the external surface to be re-painted with polymer-cement paint (2:1)
Preventive maintenance @ 4 years	Internal painting with three coats of lime wash

STONE CONCRETE BLOCKS

Stone concrete block masonry had developed seepage problems in Surangal and Sreeramnagar. Only the walls exposed to the prevailing direction of rainfall had seepage problem. In-situ testing of the blocks revealed that a few of them did not have adequate consolidation. This may be attributed to inadequate quality control and hence, it has been excluded from the life cycle analysis. As in the case of other types of exposed walling systems, stone concrete block masonry also needed some amount of re-pointing in 2000 (about 12-17% of the total wall area). Anticipating that this will increase over time, 30% of the total wall area has been assumed to be re-pointed after every ten years as in the case of rat-trap. The following table shows the life cycle impacts of stone concrete block masonry.

Table 11.15 The frequencies of corrective and preventive maintenance of stone concrete block wall.

Walling system	Stone concrete block
Corrective maintenance @ 10 years	30% of the external surface to be re-pointed with flush pointing in 1:3 cement sand mortar
Preventive maintenance @ 4 years	Internal painting with three coats of lime wash

The preventive and corrective maintenance for the coursed rubble stone has been assumed to be same as that of the stone concrete block masonry. It is important to note that the corrective maintenance requirements of the different construction technologies had varied frequencies with a minimum of ten years. One should, therefore, consider the different frequencies of occurrences of the corrective maintenance in life cycle impact assessment. However, for the simplicity of calculations, corrective interventions have been assumed to occur after every ten years in this dissertation. The reasons for assuming four years as the frequency of preventive maintenance have been explained in chapter 6.

SUMMARY OF DATABASE FOR THE LIFE CYCLE ANALYSIS OF THE WALLING SYSTEMS ADOPTED IN ANDHRA PRADESH PRIMARY EDUCATION PROJECT

Table 11.16: The specifications of the treatment and fishes on the wall surfaces

Wall treatment	**Description**	**Remarks**
Cement-sand plastering	Plastering with sponge finish - first coat in cement-sand mortar (1:5) proportion 8 mm thick and second coat cement-sand mortar (1:3) proportion 4 mm thick	Internal and/or external
Cement-sand pointing	Flush pointing in cement-sand mortar (1:3)	External
Cement stabilised mud plastering	15 mm thick mud plastering with sponge finish (1:4:8 –cement: sand: mud)	Internal and/or external
Painting	Lime washing - three coats	Internal and/or external
Polymer treatment	Latex-cement (2:1) based chemical compound	External

Source: Author

11.5 METHOD OF CALCULATING LIFE CYCLE IMPACTS

The life of a school building has been considered as 50 years according to the Bureau of Indian Standards (IS 875, Part 3, 1987). As mentioned in chapter 6 on Andhra Pradesh Primary Education Project, a discount rate of 13% has been adopted for life cycle costing, which was the fixed deposit interest rate in 1996 for a period of more than 2 years (UBI, 1996). An inflation of 8% has been adopted for calculating the net discount rate for the period 1995-96 (ICRIER, 2004). However, discussions with the fellow of the Indian Council for Research on International Economic Relations, New Delhi, revealed that some of researchers do not consider inflation to be important while calculating the nett present value. Since this dissertation's focus is not on this issue, inflation has been included in the calculations. However, it can be reset to zero in the Microsoft Excel worksheet "G" shown in Figure 1.8 (chapter 1) to recalculate the life cycle impacts without considering inflation.

The life cycle impacts of a building technology may be unpredictable since alternative waterproofing technology and interior and exterior finishes may come up in course of time, which are superior in terms of cost, embodied energy and emission than the originally adopted ones. However, in this dissertation, the same technologies have been assumed to be adopted in the 10 and 4 years' interventions for the entire 50 years life cycle of the school buildings in Ranga Reddy district. This made the calculation for life cycle impacts of the embodied energy and CO_2 emissions simple by adding the impacts of the 4 and 10 years' interventions for a period of 50 years. Based on these assumptions, the following sections describe the method of life cycle impact assessment.

11.5.1. Life Cycle Cost: Unit Cost, Retention and Labour

Miles and Syagga (1987) use the following expression for life cycle costing (they use the term 'Cost in use');

LCC = C + M + -S

C → initial capital cost

M → sum of discounted values of annual maintenance

S → scrap value of the building (discounted) - assumed to be zero in this dissertation.

LCC → Life Cycle Cost

A critical variable in this regard is the discount rate (composed of the time value of money and the effects of inflation), which affects the results significantly (Sterner, 2000). Inflation may be considered as a general increase of prices of goods and services over time in the economy as whole, without a corresponding increase in value. According to Stemer, choosing a discount rate which is too high will bias decisions in favour of short term low capital cost options, while a discount rate which is too low will give an undue bias to future cost savings. Since the accuracy of choosing a certain discount rate is uncertain, the result of a life cycle cost calculation can always be questioned. Despite this problem, there are possibilities to lessen the uncertainties in the result by performing sensitivity analysis where parameters which are of the greatest importance to the results can be varied. However, the sensitivity analysis has been excluded here since that is beyond the scope of this dissertation.

The nett present value method (NPV) of a flow of cash is a system proposed by many as the best for evaluating building-related options (Dale, 1993). The system takes into account all the apparent variables acting upon a cash stream. Dale states that Flannagan et al. (1989) express nett present value as;

$$NPV = \sum_{t=0,T} Ct/(1+r)^t$$

C is the estimated cost in year t, r is the discount rate and T is the period of analysis in years. According to Dale (1993) the 'Nett of inflation discount rate', the Ndr can be expressed as;

$$Ndr = [\ (1+ \text{discount}\ \%)/(1+\text{inflation}\%)-1\ ]$$

Discount rate =13%

Inflation = 8%

Nett Present Value (NPV) can be expressed as;

$NPV = IC + RC1/\ (1+Ndr) + RC2/\ (1+Ndr)^2 + RC3/\ (1+Ndr)^3$ ....)

IC → initial cost

RC → recurring costs in year 1, year 2 ......

The life cycle cost (LCC) is expressed as follows;

$$LCC = CBS + \sum_{n1=\text{@ 10 years } 11, 21, 31, 41} NPV_{n1} + \sum_{n2=\text{@ 4 years } 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45} NPV_{n2}$$

LCC – life cycle cost

CBS – Cost of basic structure + finishes

NPV_{n1} – nett present value of recurring cost of corrective maintenance at the rate of 10 years

NPV_{n2} – nett present value of recurring cost of preventive maintenance at the rate of 4 years

11.5.2. Life Cycle Impacts: Embodied Energy and CO_2 Emission

The embodied energy consumption and CO_2 emission of different combinations of walling and roofing systems in the whole life of the building has been calculated according to the database of Andhra Pradesh Primary Education Project. The 10 year and 4 year frequencies of interventions have been calculated and added to the initial to calculate the life cycle embodied energy and CO_2 emission impacts.

The following expressions are for calculating life cycle embodied energy.

$$LCEE = IEE + \sum_{n1 = @\,10\text{ years } 11,21,31,41} REE_{n1} + \sum_{n2 = @\,4\text{ years } 5,9,13,17,21,25,29,33,37,41,45} REE_{n2}$$

LCEE – life cycle embodied energy

IEE – initial embodied energy of basic structure + finishes

REE_{n1} – recurring embodied energy of corrective maintenance at the rate of 10 years

REE_{n2} – recurring embodied energy of preventive maintenance at the rate of 4 years

The following expressions are for calculating life cycle emission of CO_2.

$$LCE = IE + \sum_{n1 = @\,10\text{ years } 11,21,31,41} RE_{n1} + \sum_{n2 = @\,4\text{ years } 5,9,13,17,21,25,29,33,37,41,45} RE_{n2}$$

LCE – life cycle emission

IE – initial emission of basic structure + finishes

RE_{n1} – recurring CO_2 emission of corrective maintenance at the rate of 10 years

RE_{n2} – recurring CO_2 emission of preventive maintenance at the rate of 4 years

11.6 SUMMARY OF DATABASE FOR LIFE CYCLE IMPACT ASSESSMENT

Table 11.17 The life cycle impacts of the roofing systems on socio-economic and environmental parameters. Rs80 = £1.

Roofs	Unit cost	Retained	Skilled mason	Semi-skilled mason	Un skilled worker	Non-renewable	Re-newable	Waste	CO_2
	Rs./ sq. m.	Rs./ sq. m.	Rs./ sq. m.	Rs./ sq. m.	Rs./ sq. m.	MJ/ sq. m.	MJ/ sq. m.	MJ/ sq. m.	Kg/ sq. m.
Reinforced cement concrete slab	620.57	144.61	30.89	33.91	96.78	784.82	311.32	2.09	139.60
Reinforced cement concrete plank & joist	557.79	86.14	41.78	41.23	105.15	767.82	212.79	0.40	134.10
Reinforced cement concrete channel	569.58	86.40	34.99	39.79	121.57	768.04	212.79	0.40	133.48
Ferrocement channel	557.67	65.97	29.55	24.64	109.69	572.61	211.36	0.01	68.05
Micro concrete tile roofing	319.34	79.04	52.96	0.09	45.16	324.56	9.77	0.62	44.00
Hybrid slab	583.26	163.77	33.91	43.44	87.58	685.29	208.22	178.42	143.53
Filler slab	674.29	170.98	65.47	60.28	149.24	717.92	503.35	42.02	152.14
stone roof	936.94	220.70	52.95	12.02	123.54	1712.43	109.94	961.69	418.04
Jack arch	546.83	134.89	36.89	37.64	97.01	669.85	95.58	323.58	153.44
corbelled brick arch	688.59	167.58	87.76	108.49	178.55	527.28	17.97	633.56	187.32
corbelled brick pyramid	677.27	166.52	78.85	72.49	188.09	612.30	20.72	609.49	174.44

Source: Adopted from Appendix VI, Table VI.10

Table 11.18 The life cycle impacts of the walling systems on socio-economic and environmental parameters. Rs80 = £1.

Walls	Unit cost	Retained	Skilled Mason	Semi-skilled mason	Un skilled worker	Non-renewable	Re newable	Waste	CO_2
	Rs./ sq. m.	Rs./ sq. m.	Rs./ sq. m.	Rs./ sq. m.	Rs./ sq. m.	MJ/ sq. m	MJ/ sq. m	MJ/ sq. m	Kg/ sq. m
Solid brick	467.49	168.43	36.57	56.92	137.15	172.19	445.14	553.20	99.91
Rat-trap	366.29	131.67	31.31	43.97	106.29	110.24	259.40	461.00	75.50
Cement stabilised mud block	369.85	77.01	36.69	34.86	122.33	175.19	259.40	0.01	40.83
Interlocking cement stabilised mud block	324.53	60.15	15.84	17.58	73.08	239.31	202.59	0.01	44.58
Stone concrete block	370.37	69.19	31.06	31.32	128.77	256.87	256.61	0.04	50.37
Coursed rubble stone	475.87	126.09	37.83	31.32	158.80	219.39	269.84	0.01	49.01

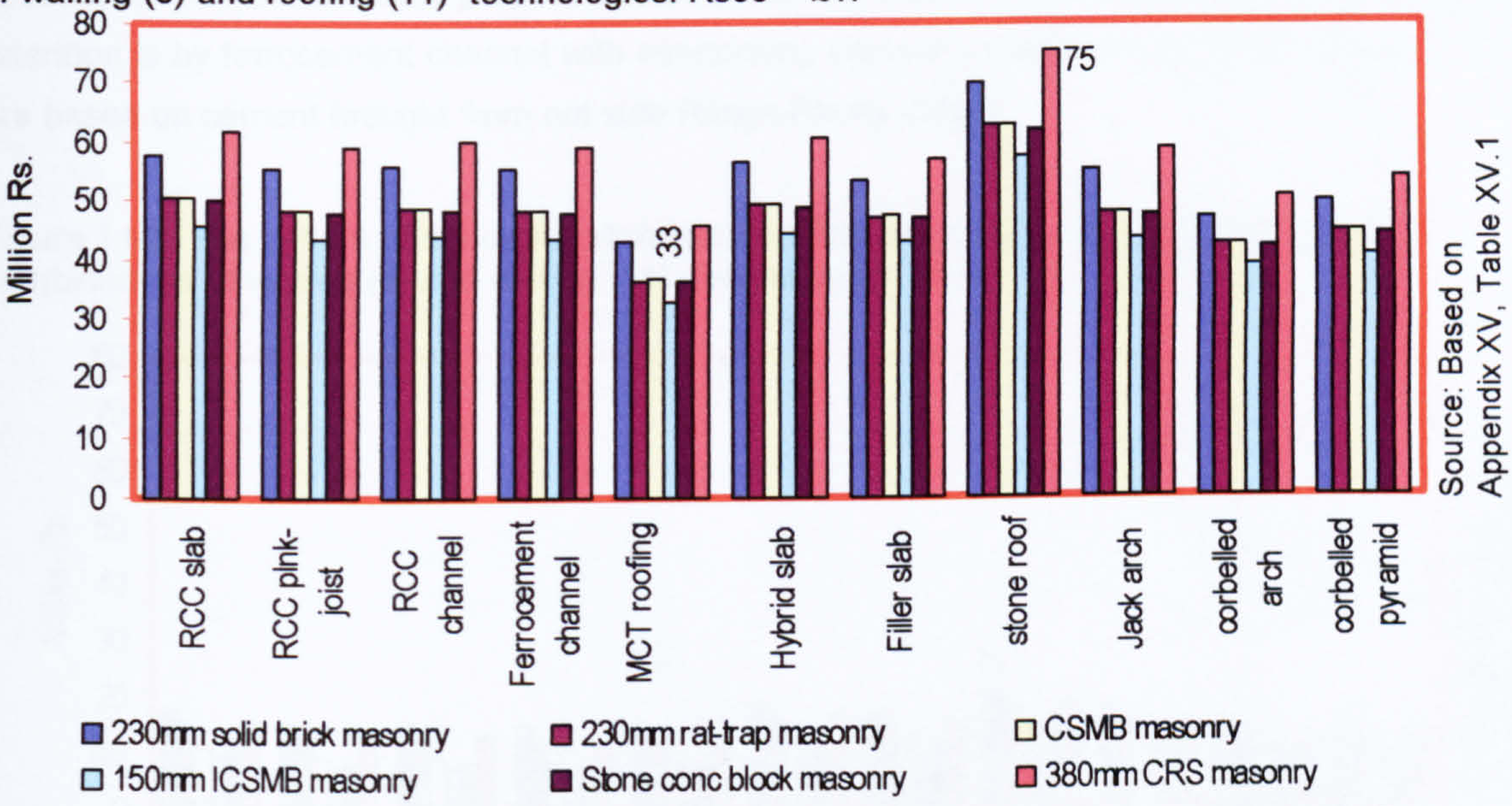
Source: Adopted from Appendix VI, Table VI.5

11.7 ANALYSIS OF LIFE CYCLE IMPACTS OF 66 COMBINATIONS OF THE WALLING AND ROOFING SYSTEMS FOR 1,068 CLASSROOMS OF 5.5M X 5.5M CARPET AREA

Based on the data on roofing and walling systems in Table 11.17 and Table 11.18 the life cycle impacts have been calculated for all 66 combinations. The following figures show the impacts under all 9 socio-economic and environmental parameters.

11.7.1. Socio-Economic Parameters: Unit Cost, Retention, Employment Opportunities for Skilled Masons, Semi-Skilled Masons and Unskilled Workers

Figure 11-1 The pattern of life cycle costs of 1,068 classroom units adopting 66 combinations of walling (6) and roofing (11) technologies. Rs80 = £1.



RCC-reinforced cement concrete, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

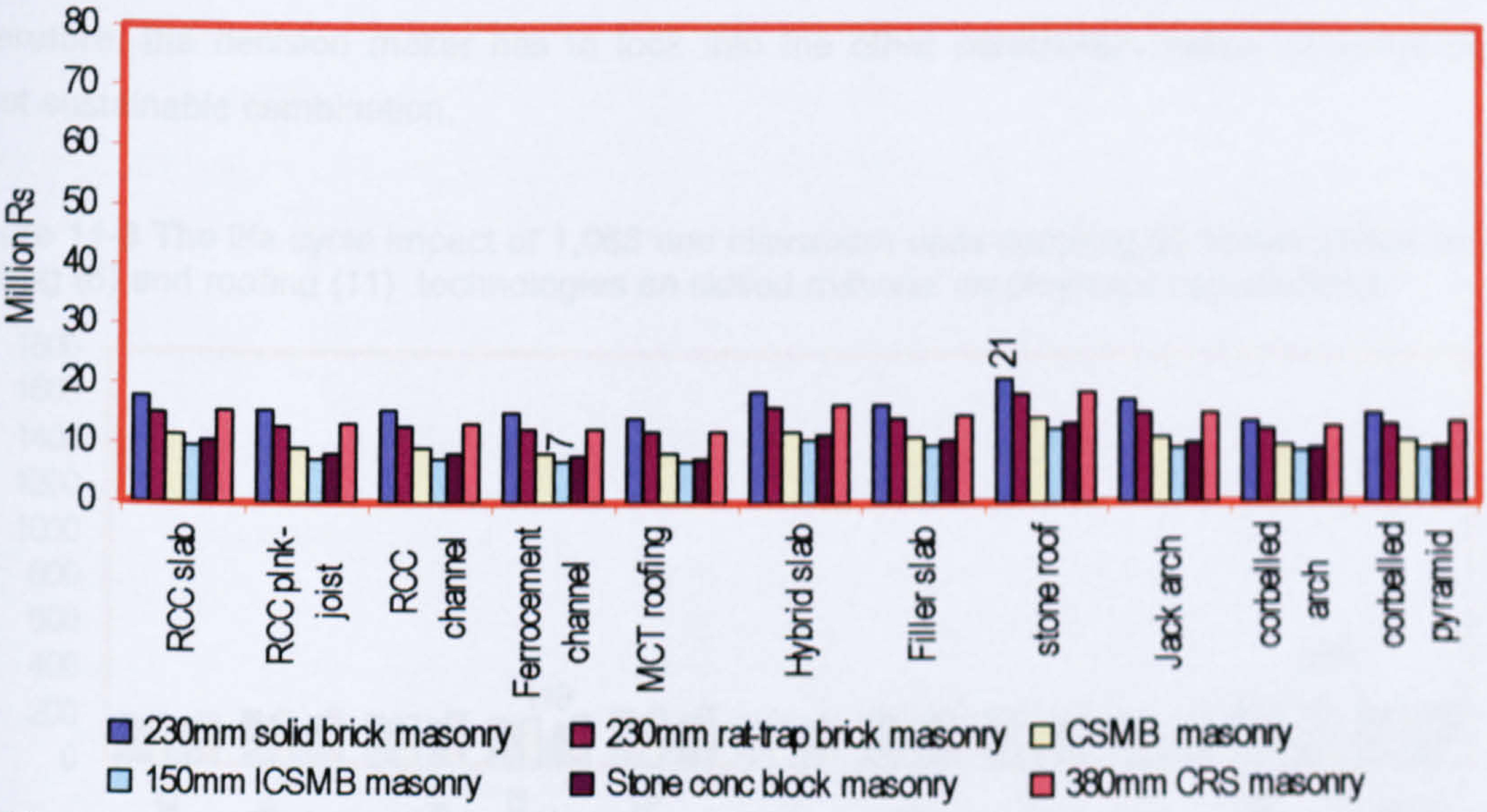
Table 11.19 The two combinations of walling and roofing systems, with maximum and minimum life cycle costs. Rs80 = £1.

	Life cycle cost in million rupees	Walling systems	Roofing systems
Maximum	75	380 mm coursed rubble stone masonry	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	33	150mm interlocking cement stabilised mud block masonry	Micro concrete tile roof with steel and timber under-structure

Figure 11-1 shows that the roofing systems in combination with solid brick and coursed rubble masonry have high life cycle costs. In contrast, all the roofs in combination with interlocking cement stabilised mud block masonry wall have low life cycle costs. The life cycle costs of roofs in combinations with rat-trap and cement stabilised mud block and stone concrete blocks are very similar. It is the highest for stone roof and coursed rubble stone wall because of the expensive brickbat coba as waterproofing treatment. If there is a cheaper and durable alternative to this, stone roof will have a lower life cycle cost. The micro concrete tile roof with interlocking cement stabilsed mud block has the least life cycle cost. Therefore, the overall pattern of life cycle costs is similar to that of the new construction (chapter 10).

Let us now look at the life cycle impacts on retention. As with chapter 10, the maximum value of retention in Figure 11-2 has been kept same as that of Figure 11-1 (80 million rupees, i.e., £1 million). This will enable one to visually compare between retention and unit cost of construction. Figure 11-2 shows that roofing systems in combination with the solid brick wall have high retention, which is followed by the combinations with rat trap and coursed rubble stone wall. The stone roof with solid brick wall retains the highest amount because of the use of locally produced brick in the wall and waterproofing system. The least retention is by ferrocement channel with interlocking cement stabilised mud block since both are based on cement brought from out side Ranga Reddy district.

Figure 11-2 The pattern of life cycle **retention** by 1,068 one classroom units adopting 66 combinations of walling (6) and roofing (11) technologies. Rs80 = £1.



Source: Based on Appendix XV, Table XV.5

RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

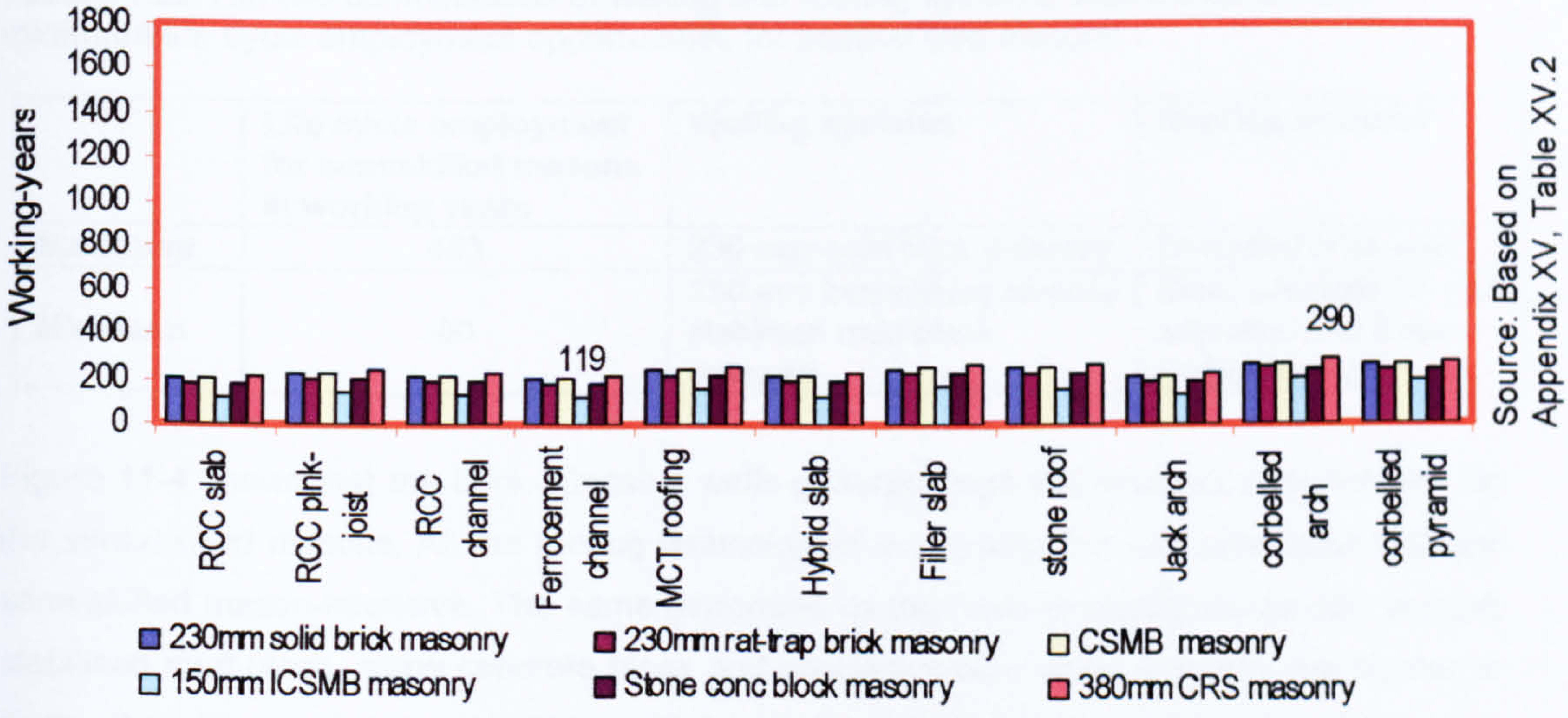
As with chapter 10, the maximum value of the labour intensities in Figure 11-2 to Figure 11-4 has been adopted as 1,600 working years. This will enable one to visually compare the skilled masons', semi-skilled masons' and unskilled workers' intensities.

Table 11.20 The two combinations of walling and roofing systems, with maximum and minimum life cycle retention. Rs80 = £1.

	Life cycle retention in million rupees	Walling systems	Roofing systems
Maximum	21	230 mm solid brick masonry	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	7	150 mm interlocking cement stabilised mud block masonry	Pre-cast ferrocement channel roofing

Figure 11-3 shows that corbelled arch roof with coursed rubble stone wall creates the highest employment opportunities for the skilled masons, which is very close to the combination of corbelled pyramid roof with the same walling. This is owing to the use of local bricks and that the corbelled roofs are skilled mason intensive. The least in this respect is the ferrocement roof with interlocking cement stabilised mud block wall. The graph shows that the skilled masons' employment opportunities generated by corbelled arch roof with coursed rubble wall is a little less than 2.5 times of the ferrocement roof with interlocking blocks. The difference in employment opportunity between the maximum and minimum has come down in 50 years of life cycle (Figure 10.4, chapter 10). Still the huge difference in skilled masons' employment generated by corbelled arch roof and coursed rubble wall will be viewed as a tremendous opportunity for improved livelihood. Figure 11-3 shows that, in terms of skilled masons' employment generation, there are other options, which are close to the best option. Therefore, the decision maker has to look into the other parameters before choosing the most sustainable combination.

Figure 11-3 The life cycle impact of 1,068 one classroom units adopting 66 combinations of walling (6) and roofing (11) technologies on skilled masons' employment opportunities.

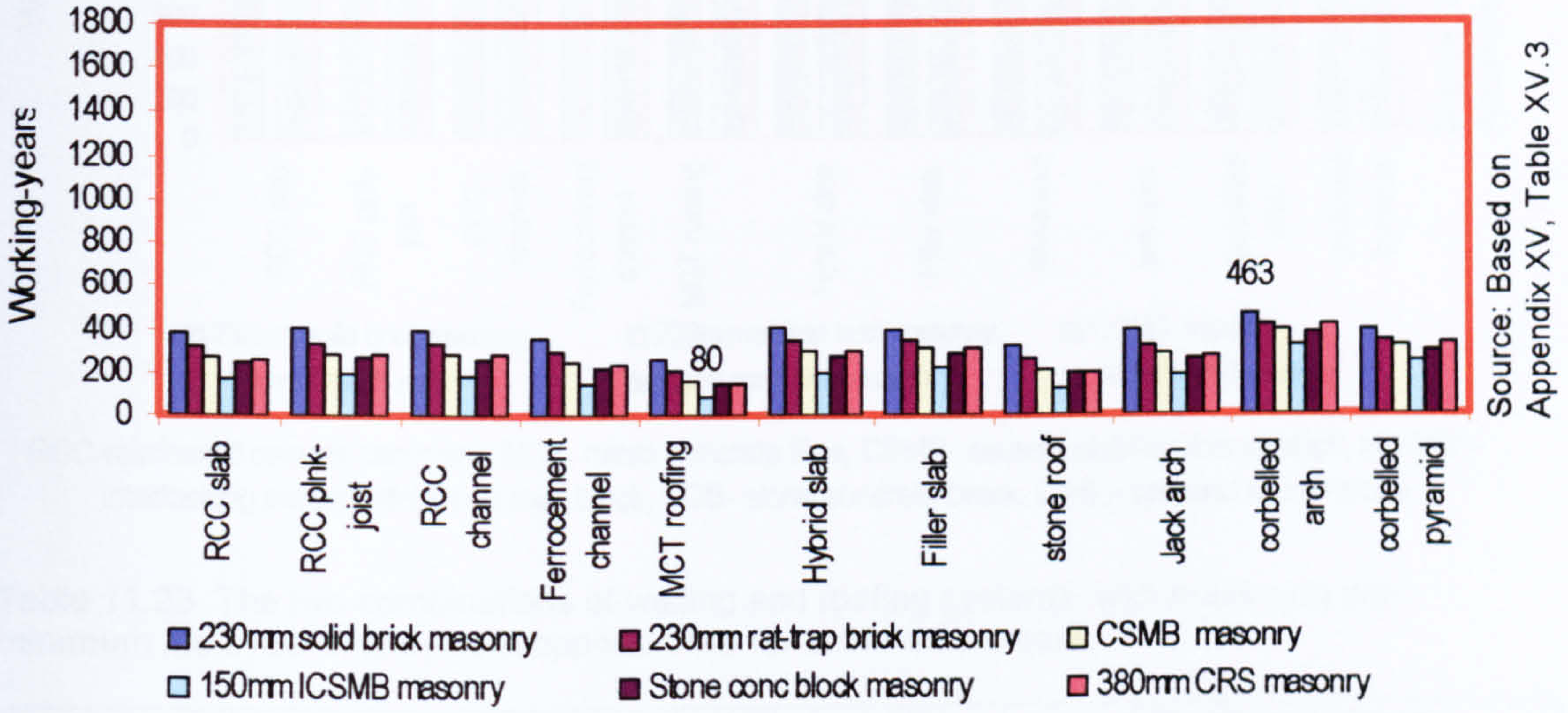


RCC-reinforced cement concrete, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Table 11.21 The two combinations of walling and roofing systems, with maximum and minimum life cycle employment opportunities for skilled masons.

	Life cycle employment for skilled masons in working years	Walling systems	Roofing systems
Maximum	290	380 mm coursed rubble stone masonry	Corbelled brick arch
Minimum	119	150 mm interlocking cement stabilised mud block masonry	Pre-cast ferrocement channel roofing

Figure 11-4 The life cycle impact of 1,068 one classroom units adopting 66 combinations of walling (6) and roofing (11) technologies on semi-skilled masons' employment opportunities.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

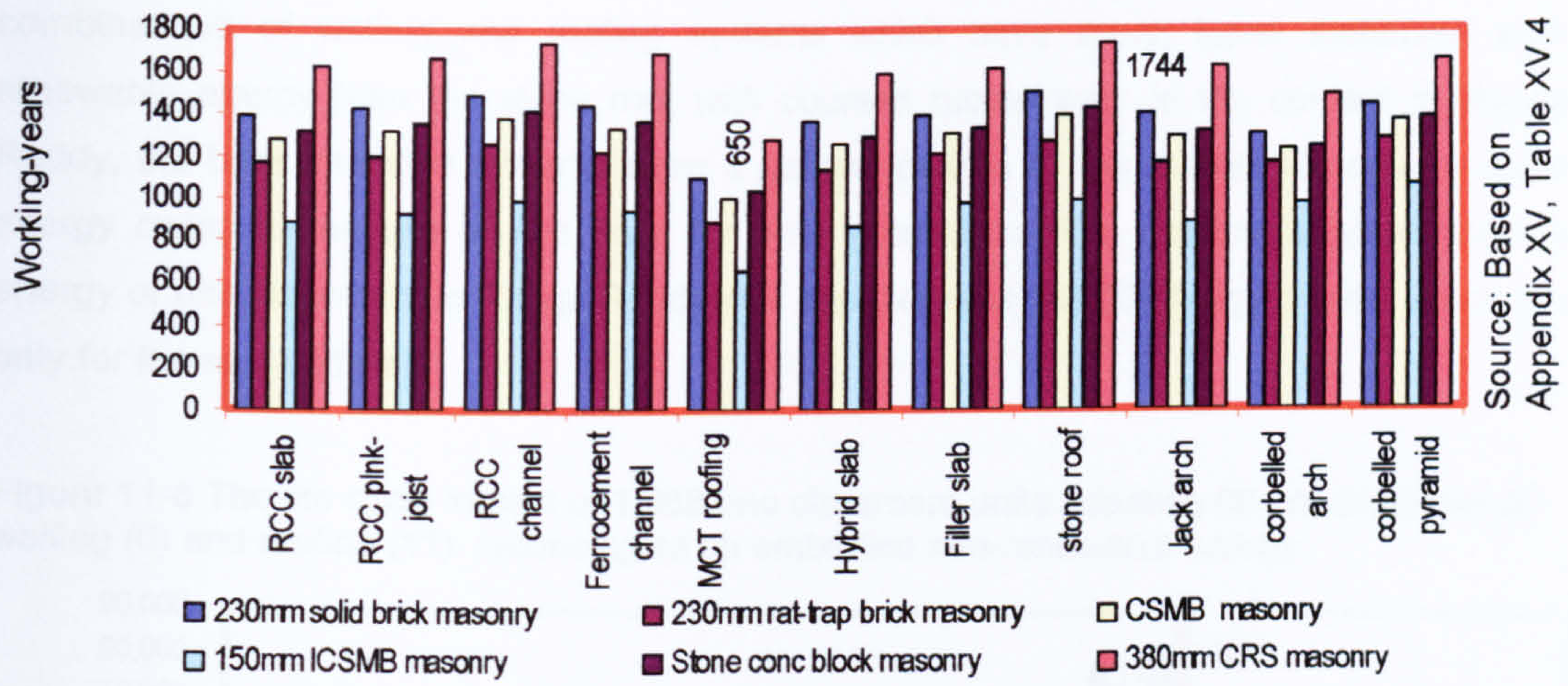
Table 11.22 The two combinations of walling and roofing systems, with maximum and minimum life cycle employment opportunities for semi-skilled masons.

	Life cycle employment for semiskilled masons in working years	Walling systems	Roofing systems
Maximum	463	230 mm solid brick masonry	Corbelled brick arch
Minimum	80	150 mm interlocking cement stabilised mud block masonry	Micro concrete tile roof with steel and timber under-structure

Figure 11-4 shows that the brick-intensive walls generate high employment opportunities for the semi-skilled masons. All the roofing technologies in combination with solid brick wall are semi-skilled mason-intensive. The same generated by the roofs in combinations with cement stabilised mud block, stone concrete block and coursed rubble stone masonry are similar to each other. The roofing combinations with interlocking blocks show a general pattern of low employment opportunity for the semi-skilled masons.

The corbelled brick arch roof generates high demand for semi-skilled masons and also skilled masons (Figure 11-3 and Figure 11-4). Therefore, a decision maker may choose corbelled arch roof and the matching wall should be coursed rubble, solid brick or rat trap depending upon their impacts under other parameters.

Figure 11-5 The life cycle impact of 1,068 one classroom units adopting 66 combinations of walling (6) and roofing (11) technologies on unskilled workers' employment opportunities



RCC-reinforced cement concrete, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Table 11.23 The two combinations of walling and roofing systems, with maximum and minimum life cycle employment opportunities for unskilled workers.

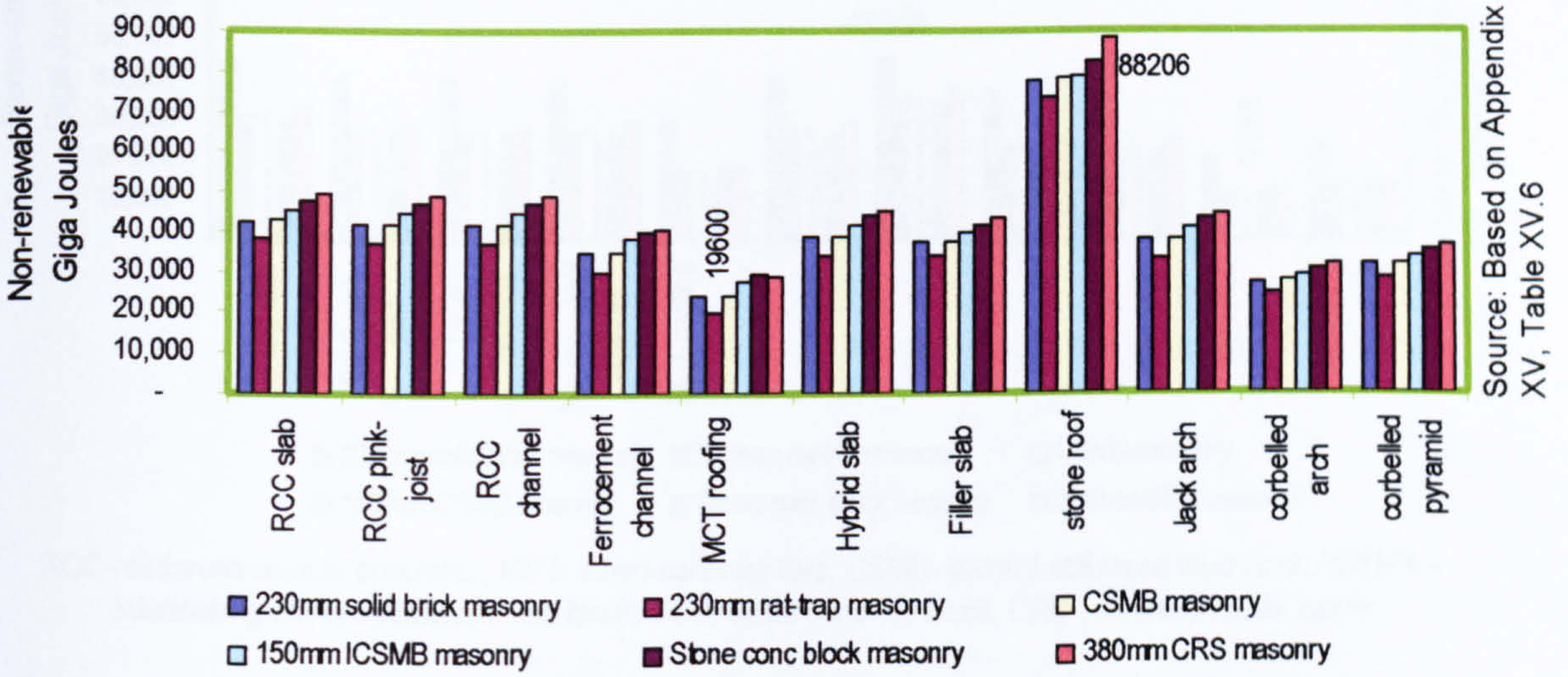
	Life cycle employment for unskilled workers in working years	**Walling systems**	**Roofing systems**
Maximum	1744	380 mm coursed rubble stone masonry	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	650	150 mm interlocking cement stabilised mud block masonry	Micro concrete tile roof with steel and timber under-structure

From the pattern of employment opportunities for the three categories of construction workers shown in Figure 11-3, Figure 11-4 and Figure 11-5, it is evident that the construction technologies adopted in Andhra Pradesh Primary Education Project were highly unskilled workers-intensive. Figure 11-5 shows that all the roofing systems in combination with coursed rubble wall are highly unskilled worker-intensive. All the roofing systems with solid brick wall are also unskilled worker-intensive. Although stone roof with coursed rubble wall generates the highest employment opportunities for the unskilled worker, its (rubble wall) combination with reinforced cement concrete channel (Rs.1735, i.e., £21.69) is close in this regard. In a context of low level skill with high unemployment problem, coursed rubble stone wall may be recommended with an appropriate roof depending upon their impacts under other parameters.

11.7.2. Environmental Parameters: Embodied Non-Renewable, Renewable, Waste Energy and Co_2 Emission

We shall now examine the environmental parameters. Figure 11-6 shows that all the walls in combination with stone roofing have high embodied non-renewable energy. The highest embodied energy is in stone roof with coursed rubble wall, which is 4.5 times more than that of micro concrete tile roofing with rat-trap wall. The figure shows that there are many combinations of walling and roofing systems which have much lower embodied non-renewable energy than the stone roof with coursed rubble wall. In the context of Ranga Reddy, the brick intensive systems show a general pattern of low embodied non-renewable energy owing to the use of rice husk for brick production. The maximum non-renewable energy of one classroom in Ranga Reddy was approximately 83,000 Mega Joules, which it is only for the roof and wall.

Figure 11-6 The life cycle impact of 1,068 one classroom units adopting 66 combinations of walling (6) and roofing (11) technologies on embodied non-renewable energy.



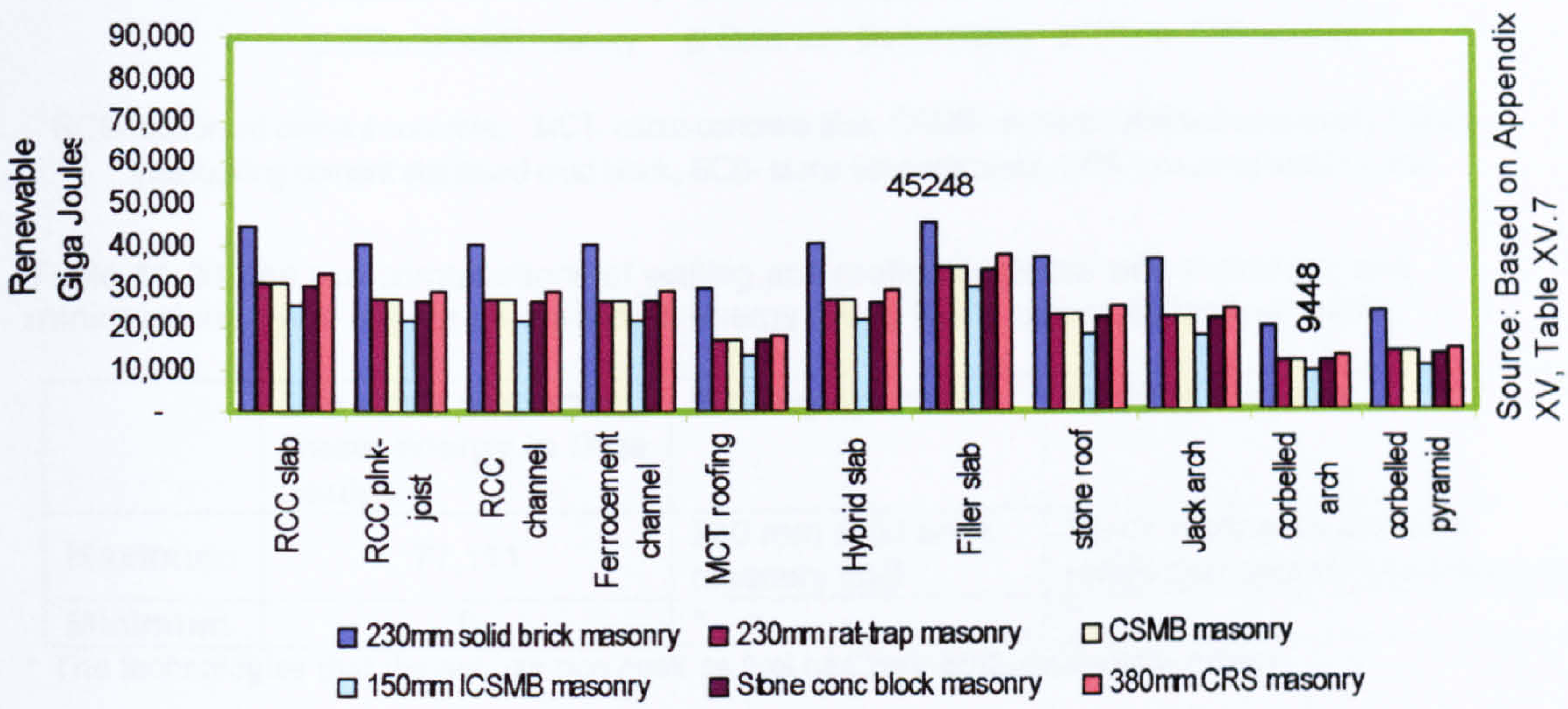
RCC-reinforced cement concrete, MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Table 11.24 The two combinations of walling and roofing systems, with maximum and minimum life cycle impact on embodied non-renewable energy.

	Life cycle embodied non-renewable energy in Giga Joules	Walling systems	Roofing systems
Maximum	88,206	380 mm coursed rubble stone masonry	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	19,600	230 mm rat-trap bonded brick masonry	Micro concrete tile roof with steel and timber under-structure

Figure 11-7 shows that all the roofing technologies in combinations with solid brick wall have high embodied renewable energy. This is owing to the use of wooden scaffolding in new construction and maintenance of this type of walling system. Figure 11-7 also shows that all the roofs with rat-trap, cement stabilised mud block and stone concrete block wall have almost the same level of embodied renewable energy. It is to be noted that, except solid brick wall, all other walls in combination with corbelled brick arch and corbelled brick pyramid show a very low embodied renewable energy. Interlocking cement stabilised mud block wall in combination with corbelled brick arch and pyramid appear to be the most environment friendly from the point of renewable energy consumption. The highest embodied renewable energy is consumed in filler slab with solid brick wall.

Figure 11-7 The life cycle impact of 1,068 one classroom units adopting 66 combinations of walling (6) and roofing (11) technologies on embodied renewable energy



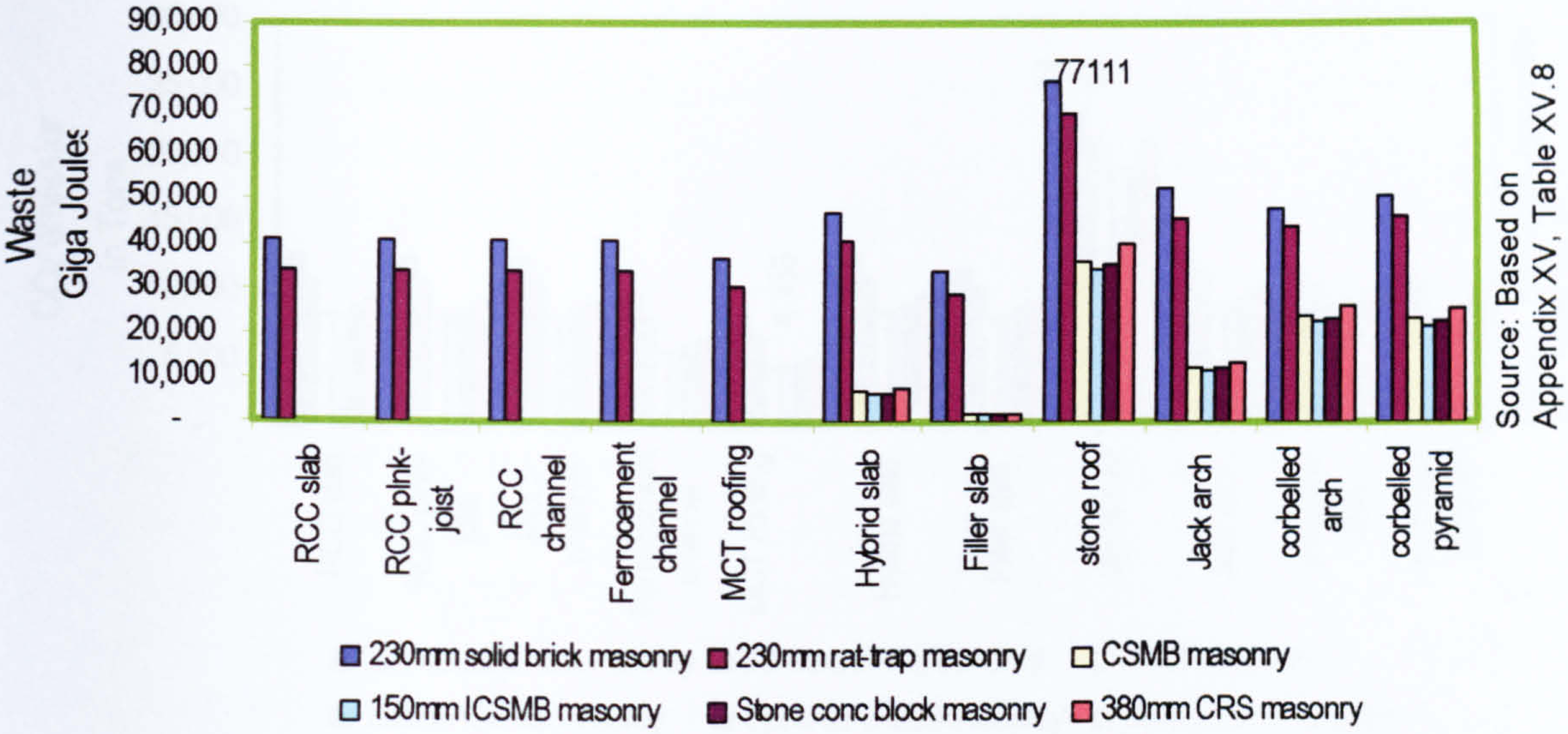
RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Table 11.25 The two combinations of walling and roofing systems, with maximum and minimum life cycle impact on embodied renewable energy.

	Life cycle embodied renewable energy in Giga Joules	Walling systems	Roofing systems
Maximum	45,248	230 mm solid brick masonry wall	Filler slab
Minimum	9,448	150 mm interlocking cement stabilised mud block masonry	Corbelled brick arch

Figure 11-8 shows that all the roofing technologies in combinations with solid brick and rat-trap wall have high embodied waste energy. The stone roofing with brick walls consume the highest quantities of rice husk and thus is the most energy efficient. However, this is valid for Ranga Reddy district only, where rice husk is used as a fuel for brick making. It is important for the decision makers to encourage this trend by recommending brick-intensive systems wherever waste-based brick production systems exist.

Figure 11-8 The life cycle impact of 1,068 one classroom units adopting 66 combinations of walling (6) and roofing (11) technologies on embodied energy from agriculture waste.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

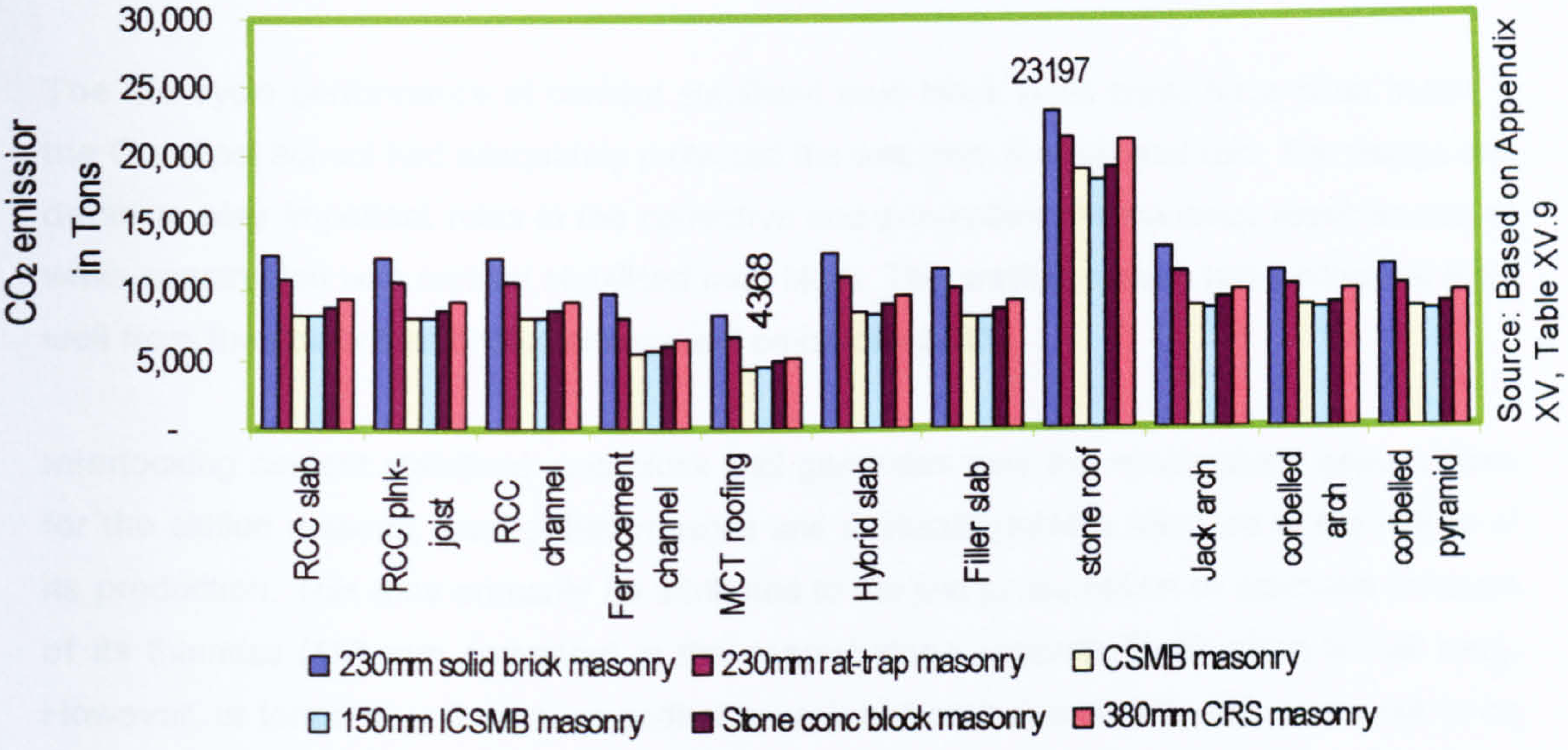
Table 11.26 The two combinations of walling and roofing systems, with maximum and minimum life cycle impact on embodied energy owing to the use of agriculture waste.

	Life cycle embodied waste energy in Giga Joules	Walling systems	Roofing systems
Maximum	77,111	230 mm solid brick masonry wall	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	0	*	*

* The technologies that did not use rice husk as fuel had zero embodied waste energy.

Figure 11-9 shows that all the roofing technologies in combinations with solid brick wall have high CO_2 emissions. The stone roof with all combinations of walling systems emits large quantities of CO_2. The CO_2 emission by stone roof with solid brick wall is 5.3 times more than that of the cement stabilised mud block and micro-concrete tiles roof. While the brick intensive systems in Ranga Reddy may appear to be environment friendly from the point of embodied energy, they are damaging to the eco system because of their high CO_2 emission. The most CO_2 emission-friendly combinations are micro concrete tile roofing with cement stabilised and interlocking cement stabilised mud block wall. The decision makers may consider this as an important issue not only because some technologies are cleaner than the others, it may also give an opportunity to the Government of India to earn by doing carbon trading.

Figure 11-9 The life cycle impact of 1,068 one classroom units adopting 66 combinations of walling (6) and roofing (11) technologies on CO_2 emission.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Table 11.27 The two combinations of walling and roofing systems, with maximum and minimum life cycle impact on CO_2 emission.

	Life cycle CO_2 emission in tons	Walling systems	Roofing systems
Maximum	23,197	230 mm solid brick masonry wall	Stone roofing on pre-cast reinforced cement concrete joists
Minimum	4,368	Cement stabilised mud block wall	Micro concrete tile roof with steel and timber under-structure

11.8 SUMMARY OF FINDINGS

The life cycle analysis carried out in this chapter has shown that there is a wide variation of impacts on socio-economy and environment by 1,068 one classroom units constructed with 66 combinations of walling and roofing technologies. The analysis reveals that the life cycle impacts are largely dependent on the type of roof and wall treatment to make them waterproof. Stone roof with low unit cost could have been the most suitable technology in Ranga Reddy district. However, it scored low because brickbat coba has been adopted as a waterproofing treatment, which is costly and also non-renewable energy intensive. While this type of waterproofing is as costly as the unit cost of the stone roof itself, it provides a thermally comfortable teaching-learning space.

As opposed to the prevailing notion that solid brick wall is inefficient, the analysis shows that it is one of the sustainable options in the context of Ranga Reddy district, where rice husk is used as fuel for brick production. However, rat trap is more energy and emission efficient than the solid brick wall.

The life cycle performance of cement stabilised mud block walls could have been better, if the Gandipet school had adequately protected the wall from the sun and rain. The design and detailing play important roles in the corrective and preventive maintenance requirements of walls constructed with cement stabilised mud block. This walling system has performed quite well from the point of embodied energy and emission of CO_2.

Interlocking cement stabilised mud block wall generates very low employment opportunities for the skilled masons, semi-skilled masons and unskilled workers because of the nature of its production. This may primarily be attributed to the low consumption of materials because of its thinness (150 mm compared to the nearest stone concrete block which is 190 mm). However, in terms of unit cost, embodied energy and emission of CO_2, this came out to be the most sustainable solution.

Among the roofs, the corbelled brick arch and pyramid have both performed well. However, corbelled arch has been slightly superior to the pyramids. These two technologies could have been sustainable options in other contexts as well, if there were a better alternative to the 1:4 cement sand mortar as waterproofing.

11.9 SUMMARY CHART

Technology change has a great bearing on the life cycle impacts. Development of a cheaper and more durable variety of waterproofing material will make the future life cycle impacts very different. Therefore, it appears that life cycle analysis is a dynamic process rather than a static and one-time fixed figure for decision making. One should attempt to use reversible treatments of the walling and roofing systems so that any new development could be adopted to enhance the life cycle performance of the roofing and walling systems. Apart from these, change in discount and inflation rates will also have bearing on life cycle analysis. There is a need for continuous evaluation of buildings for their life cycle implications, which would vary significantly with development of new technologies.

The above graphs have been analysed to understand the life cycle impacts of constructing 1,068 one classroom units using 66 combinations of walling and roofing technologies. The summary of the analysis has been presented in Table 11.28 which will provide an overall picture of the best and worst combinations of walling roofing systems from the point of view of life cycle impacts.

Table 11.28 The summary chart - ☑means the most favourable option and ☒ means the least favourable option

WALLING **ROOFING**	230 mm solid brick wall	230 mm rat-trap bonded brick wall	230 mm cement stabilised mud block wall	150 mm interlocking cement stabilised mud block wall	Stone concrete block wall	380 mm coursed rubble stone masonry wall
1. Reinforced cement concrete in-situ						
2. Reinforced cement concrete plank and joist						
3. Reinforced cement concrete channel						
4. Pre-cast ferrocement channel roofing				2☒, 3☒		
5. Micro concrete tile roof with steel and timber under-structure		6☑	9☑	1☑ 4☒, 5☒		
6. Hybrid						
7. Reinforced cement concrete filler slab	7☒					
8. Stone roofing on pre-cast reinforced cement concrete joists	2☑, 8☑ 9☒					1☒, 5☑, 6☒
9. Jack arch on pre-cast reinforced cement concrete joists.						
10. Brick corbel arch	4☑			7☑		3☑
11. Brick pyramid						

Legends : unit cost (1), retention (2), skilled (3), semi-skilled (4), unskilled (5), non-renewable energy (6), renewable energy (7), waste (8) and CO_2 emission (9).
Based on the Figure 11-1 to Figure 11-9

Table 11.28 shows the most favourable and the least favourable life cycle combinations of walling and roofing systems. The method of making this table is similar to the Table 10.11 in the last chapter. This chart gives an opportunity for decision makers to compare the impacts of new construction and the life cycle impacts of the 1,068 one classroom units constructed with 66 walling and roofing technologies. As in Table 10.11, The numbers attached with each tick or cross mark denotes the parameter number, viz., **1, 2, 3, 4, 5, 6, 7, 8, 9** for the unit cost, retention, skilled, semi-skilled, unskilled, non-renewable energy, renewable energy, waste and CO_2 emission. The decision maker will ideally consider those options where only tick marks exist. At this point it is important to compare the results of the life cycle assessment with that of the new construction. The main differences between the new construction and life cycle impacts are as follows.

Table 11.29 Significant variations between the new construction and life cycle impacts of 1,068 one classroom units adopting 66 combinations of walling and roofing technologies. This table is to be read in conjunction with Table 10.11 of chapter 10.

Row no.	Row- items	The changed situation with respect to the new construction as shown in Table 10.11
1-3	Reinforced cement concrete in-situ, plank and joist, channel	No change
4	Ferrocement roof	No change
5	Micro concrete tile roof with rat trap wall	In addition to the existing features, life cycle non-renewable energy of the micro concrete tile roof with rat-trap wall scores the highest.
6	Hybrid	Table 10.11 shows that hybrid with 230 mm solid brick wall is the best option for retention, which is not the case in life cycle retention.
7	Filler slab	Table 10.11 shows that filler slab with 380 mm course rubble wall is the least favourable option in embodied renewable energy. In life cycle embodied renewable energy, the combination of least favourable option has changed to filler slab with 230 mm solid brick wall.
8	Stone roofing	A drastic change
9	Jack-arch	Table 10.11 shows that the best option in embodied waste energy is jack-arch with solid brick wall. In life cycle, no wall combinations with jack arch score either the best or the least favourable options.
10	Corbelled brick arch roof	From the existing features, the corbelled brick arch roof with rat trap wall as the best option in non-renewable energy is no longer valid in life cycle analysis.
11	Corbelled brick pyramid	No change.

Source : Author

The summary in Table 11.28 and Table 11.29 will help a decision maker to understand the life cycle impacts in a particular context. These two will enable her/him to choose those technologies, which have low unit cost, high retention, high income generation, low embodied energy, high embodied waste energy and cause low emission of CO_2. While these will help the decision maker to form an idea on the scale of impacts in a particular context, she/he would like to know the best combination of walling and technologies for a particular location. Therefore, there is a need for using the evaluation method developed in chapter 7, which has been shown in the next chapter.

CHAPTER 12 ANALYSIS OF THE SCORES

The last two chapters have shown the extent of socio-economic and environmental impacts in terms of actual quantities. For example, if 1,068 classroom units are constructed with 66 combinations of walling and roofing systems, the highest life cycle CO_2 emission is 23,000 tons. However, for the new construction of same number of classroom units, the highest CO_2 emission is 11, 500 tons. Such differences are significant. The previous two chapters have shown that the differences of impacts between the life cycle and new construction of other eight parameters are also significant. While this type of quantitative impacts will increase awareness of the decision makers and also make the process transparent to them, they would still like to know the best option in a particular context. Therefore, this chapter will adopt the evaluation method developed in chapter 7 to demonstrate how one can choose the best option in a particular context.

12.1 METHOD OF SCORING

The District Primary Education Programme has been adopted for life cycle impact analysis, which means an investment of 100 million rupees (£1.25 million) in a district. As explained in chapter 7, the nine socio-economic and environmental parameters have been assumed to be the examination papers. Each walling and roofing combination has been assumed to be a student in a classroom, who will be examined against the nine exam papers. Therefore, there are 66 combinations as students in a class appearing for the nine examination papers. The units of the first five parameters are in rupees; the sixth to eighth are in Mega Joules and the ninth in tons. Following the principles of Rolfsman (2002), the first five have been examined by costs and the remaining by consumptions and emissions. The index method of scoring has eliminated the problem of nine parameters having different units.

It may be recalled that the following expression for calculating the weighted index of j^{th} technology (walling and roofing combinations) has been developed in chapter 7.

$$WIT_j = \sum_{\text{For } k=1}^{\text{to } 5}\left(SCT_{kj} \times WP_k\right) \times GW1 + \sum_{\text{For } k=6}^{\text{to } 9}\left(SCT_{kj} \times WP_k\right) \times GW2$$

For $j = 1, n$

Socio-economic Group weighting – GW1 Environmental Group weighting - GW2

Subject weighting –WP_k, k = 1 to 5 Subject weighting –WP_k, k=6 to 9

SCT_{kj}, is the subject score where k=1 to 9 indicate the parameters for technologies j= 1 to "n".

WIT_j, (j=1,n) is the general expression of the final weighted index.

From the final weighted index (WIT_j, j=1,n), the highest element will be assumed to have an index of 100 and the remaining indexes will be calculated accordingly. As mentioned before, there are sixty six combinations of wall and roof, which will be evaluated. For the convenience of interpreting, indexes of the 66 combinations will be presented as 11x6 matrix.

Under the socio-economic parameters, the combination of wall and roof that has the minimum unit cost has been assumed to score 100. Based on that, the indexes of the remaining 65 combinations have been calculated. In a similar manner, under the environmental parameters, the roofing and walling combination with minimum embodied non-renewable energy has been considered 100 and the indexes of the remaining 65 combinations have been calculated with respect to that. Table 7.3 of chapter 7 shows the conditions under which the remaining seven parameters will score 100. Thus, the nine indexes obtained by each combination could be summed up to get the aggregate. Finally the highest aggregate has been assumed to score 100 and the indexes of the remaining 65 have been calculated as before.

12.2 WEIGHTS

It is important to note that the issue of best solution in a context is dependent on the weighting associated with each of the nine parameters considered in this dissertation. It will also depend upon the socio-economic and environmental group weightings shown in chapter 7 (section 7.5). It has already been discussed in chapter 1, chapter 2 and chapter 7 that weighting systems are fraught with difficulty since they cannot be accomplished with complete, or in some cases, any, scientific objectivity (Todd et al 2001). According to Todd's suggestion, which is based on Dickie and Howard (2000), 'consensus-based' weighting has been suggested which will be done by a group of specialists. It is suggested that, in a development programme such as the District Primary Education Programme, a team of specialists consisting of educationist, pedagogue, economist, sociologist, civil engineer, architect, administrator, community, etc., will assign the weights to the nine parameters.

In this dissertation, the effect of varying weightings on the scores has been demonstrated instead of recommending them. Let us examine this first. In the index method, if we assign any set of weightings to the nine parameters, the highest score by a particular combination of walling and roofing technology will always be 100. Whereas the lowest index, which is relative to the highest score, will vary as the weightings of the parameters change. Therefore, it is necessary to examine the effect of the weights on the lowest index which has been studied as follows.

- For simplicity, a geometrical progression series viz., 1,2,4,8,16,32,64,128, 256,512,1024, .. etc. has been adopted as increasing weightings. This series magnifies the weights rapidly while studying the effect of the weight on the pattern of lowest scores.

- When all the weights are equal to "1", the minimum index is 60 (Figure 12-3).

- While the weights of a particular parameter, e.g., unit cost are varied as 2, 4, 8, 16 ....1024, the weightings of the remaining parameters are kept as constant (equal to 1). All the minimum scores are calculated and recorded for each weight of unit cost. The formula in section 12.1 has been used for the lowest index calculation.

- Similarly, weightings of the next parameter, e.g., skilled mason are varied as 2, 4, 8, 16 ....1024, keeping the weightings of the remaining parameters as constant (equal to 1). All the minimum scores are calculated and recorded for each weight of skilled mason.

- The process is repeated for the remaining seven parameters and all the minimum scores are calculated and recorded.

This is carried out for both life cycle and new construction. The lowest indexes with respect to the increasing weightings of the nine parameters have been calculated based on the data in Table 12.1 and the results are shown in Figure 12-1 and Figure 12-2.

Table 12.1 The discount rate, inflation rate and group-weights considered for the calculations of the lowest index for new construction and life cycle impacts.

Discount rate		13%
Inflation rate		8%
Socio-economic	GW-1	1
Environmental	GW-2	1

Figure 12-1 The pattern of lowest indexes for different weights assigned to the nine parameters.

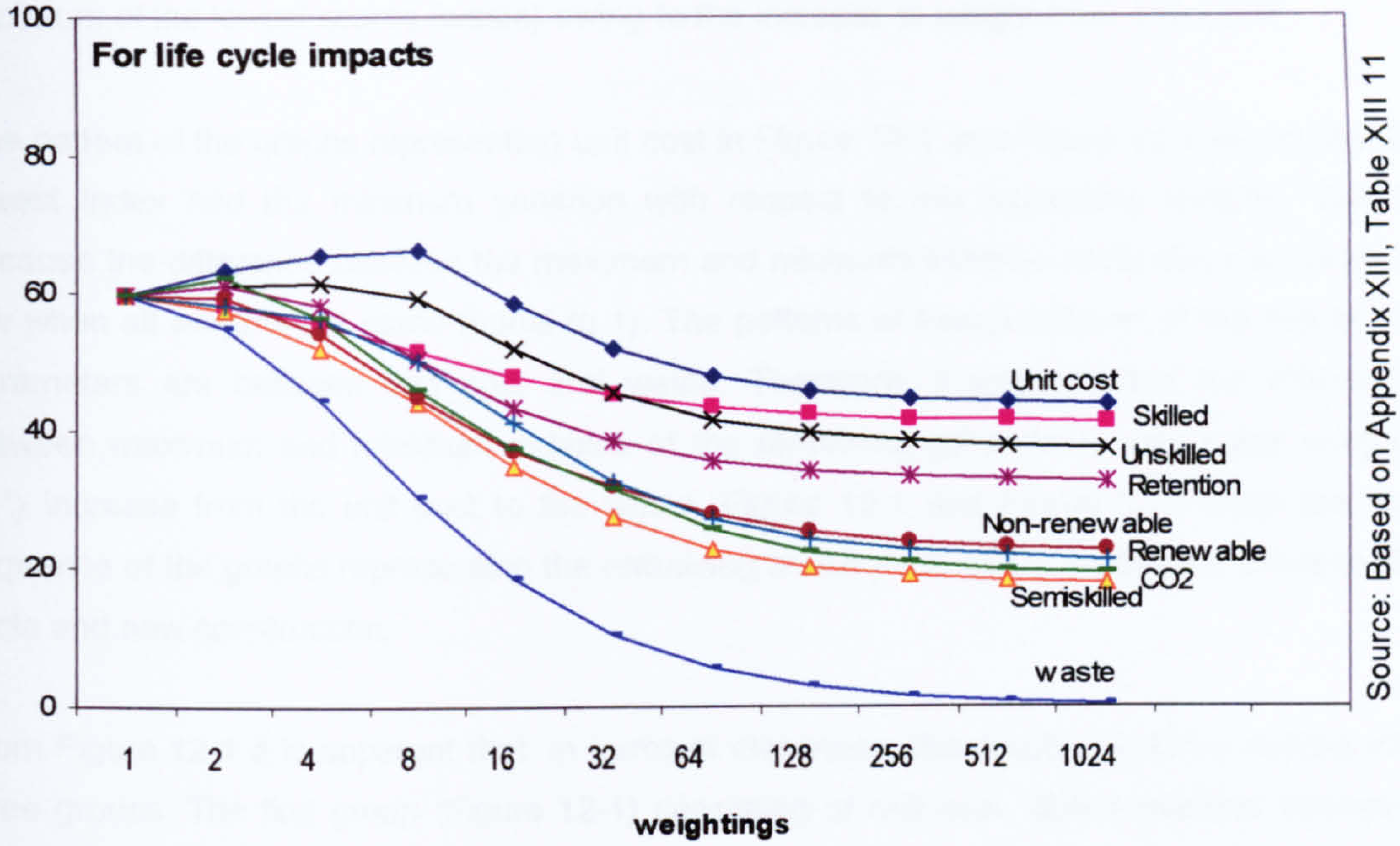
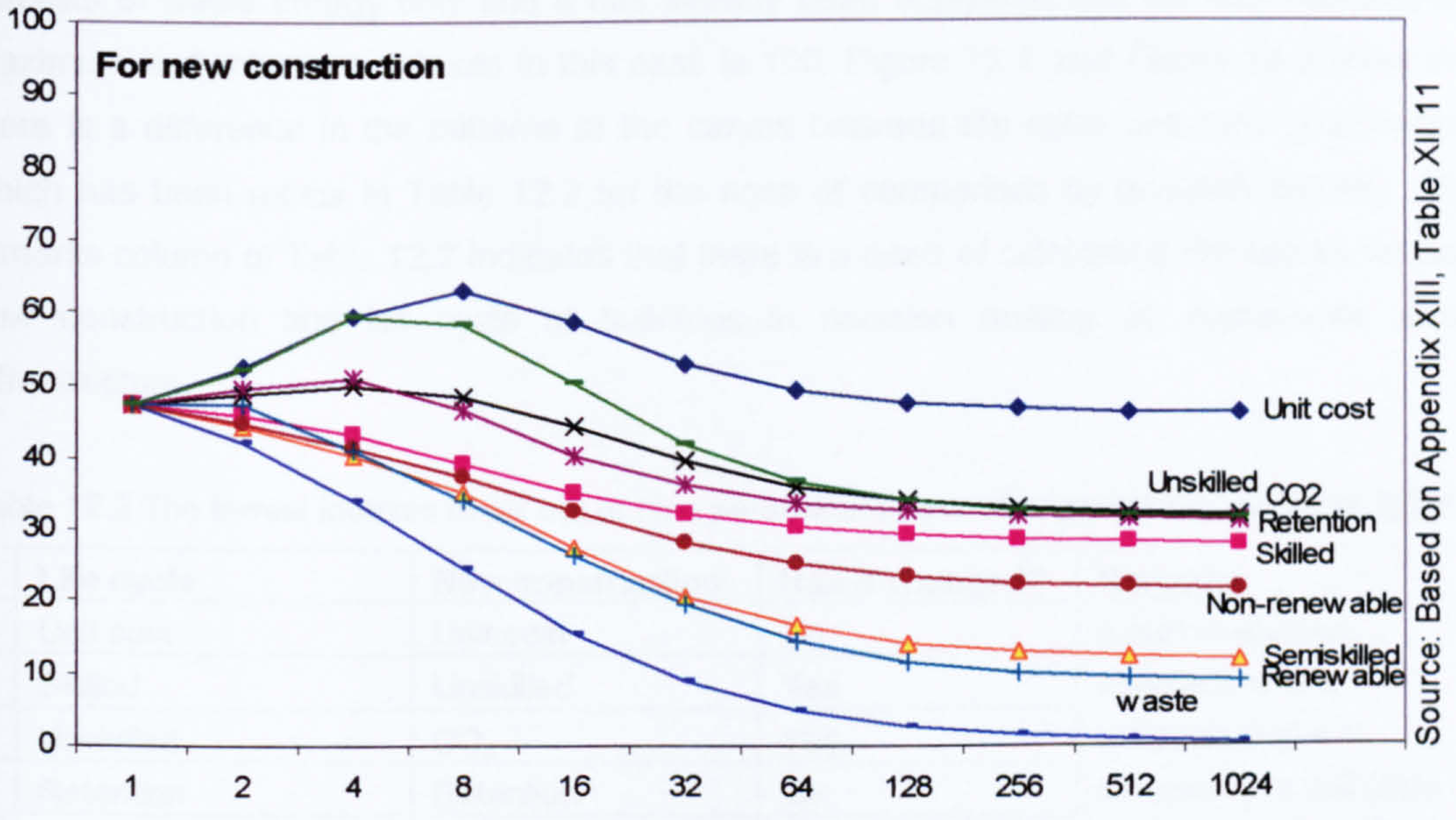


Figure 12-1 shows that the curves tend to be parallel to the x-axis from 128 onwards. The same pattern is observed also in Figure 12-2 for new construction. Therefore, 128 may be adopted for scoring.

Figure 12-2 The pattern of lowest indexes for different weights assigned to the nine parameters.



The most significant difference between the maximum and minimum of the lowest indexes is observed in the graph representing parameter waste (Figure 12-1 and Figure 12-2). It may be noted that only the bricks and clay tiles in Ranga Reddy had embodied waste energy. The condition for an index of 100 under this parameter is the maximum embodied waste energy consumption of a technology. Therefore, only the technologies based on bricks or tiles scored highly and the remaining, e.g., reinforced cement concrete slab with stone concrete block wall, etc., had zero index. That is why there is such a high difference between maximum and minimum of the lowest scores (waste) owing to the increase in weight from 1 to 1,024.

The pattern of the graphs representing unit cost in Figure 12-1 and Figure 12-2 shows that its lowest index had the minimum variation with respect to the increasing weights. This is because the difference between the maximum and minimum indexes under this parameter is low when all weights are same (equal to 1). The patterns of lowest indexes of the rest of the parameters are between unit cost and waste. Therefore, it appears that the difference between maximum and minimum indexes of the remaining parameters with equal weights ("1") increase from the unit cost to the waste. Figure 12-1 and Figure 12-2 show that the sequence of the graphs representing the remaining seven parameters is different between life cycle and new construction.

From Figure 12-1 it is apparent that, in terms of closeness, the graphs could be divided into three groups. The first group (Figure 12-1) consisting of unit cost, skilled masons' intensity, unskilled workers' intensity and retention are close to each other at a weight of 1,024. Therefore, the difference between maximum and minimum indexes (for equal weights) of this group is low. The second group (Figure 12-1) consisting of non-renewable energy, renewable energy, CO_2 emission and semi-skilled workers' employment have a wider gap between the minimum and maximum scores (for equal weights) than the first group. The last group consists of waste energy only and it has already been explained that the gap between the maximum and minimum indexes in this case is 100. Figure 12-1 and Figure 12-2 show that there is a difference in the patterns of the curves between life cycle and new construction, which has been recast in Table 12.2 for the ease of comparison by decision makers. The remarks column of Table 12.2 indicates that there is a need of calculating the scores for both new construction and life cycle of buildings in decision making on sustainable social infrastructure.

Table 12.2 The lowest indexes of six out of nine parameters have changed at the weight of 1,024.

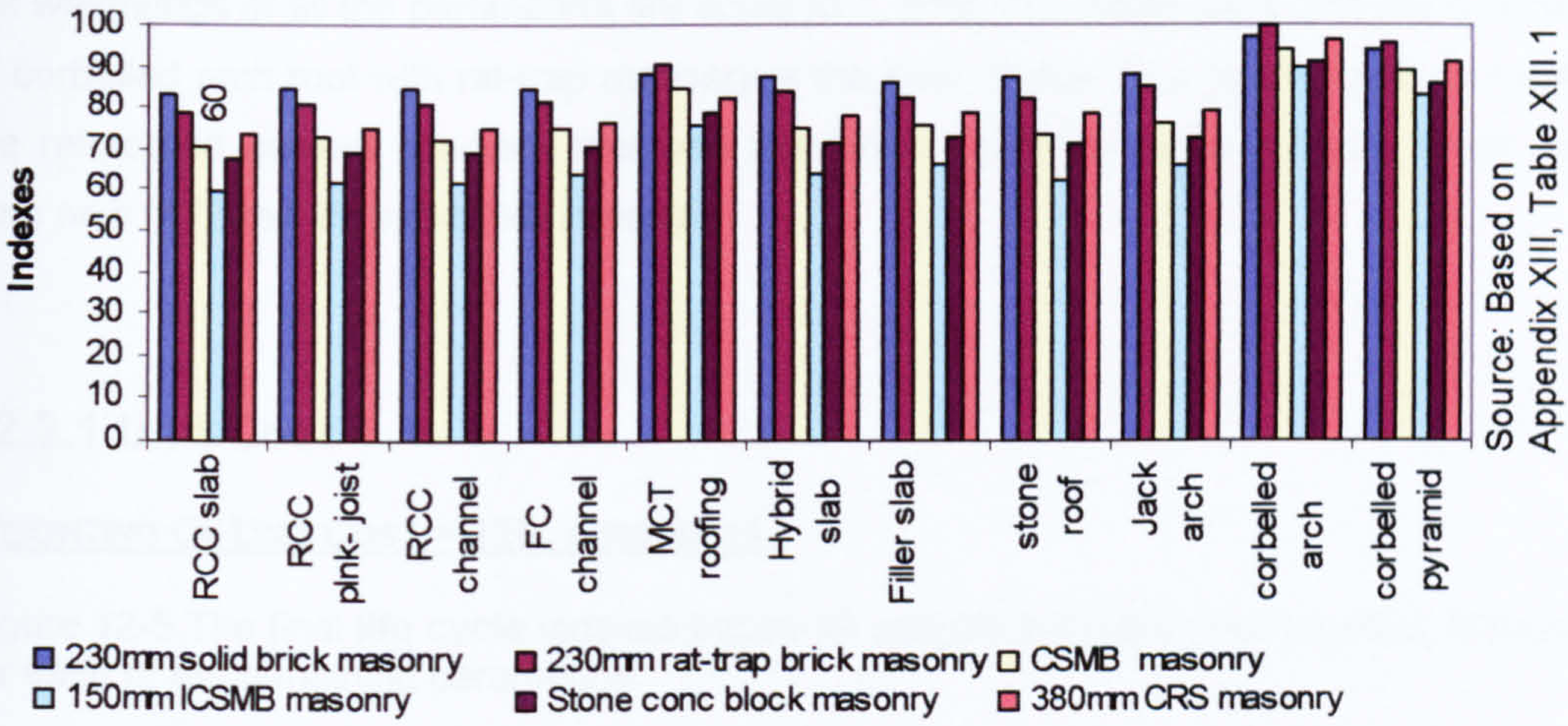
	Life cycle	New construction	Has it changed?	Remarks
1	Unit cost	Unit cost	No	6 out of nine has changed, which indicates that it is necessary to calculate scores of both new and life cycle of buildings.
2	Skilled	Unskilled	Yes	
3	Unskilled	CO_2	Yes	
4	Retention	Retention	No	
5	Non-renewable	Skilled	Yes	
6	Renewable	Non-renewable	Yes	
7	CO_2	Semiskilled	Yes	
8	Semiskilled	Renewable	Yes	
9	Waste	Waste	No	

12.3 ANALYSIS OF INDEXES

This section will show the indexes of the 66 combinations of roofing and walling systems based on the impacts of 1,068 one-classroom units in Ranga Reddy district. These have been calculated based on the formula and the method outlined in section 12.1. The database and the assumptions are same as in chapter 10 and 11.

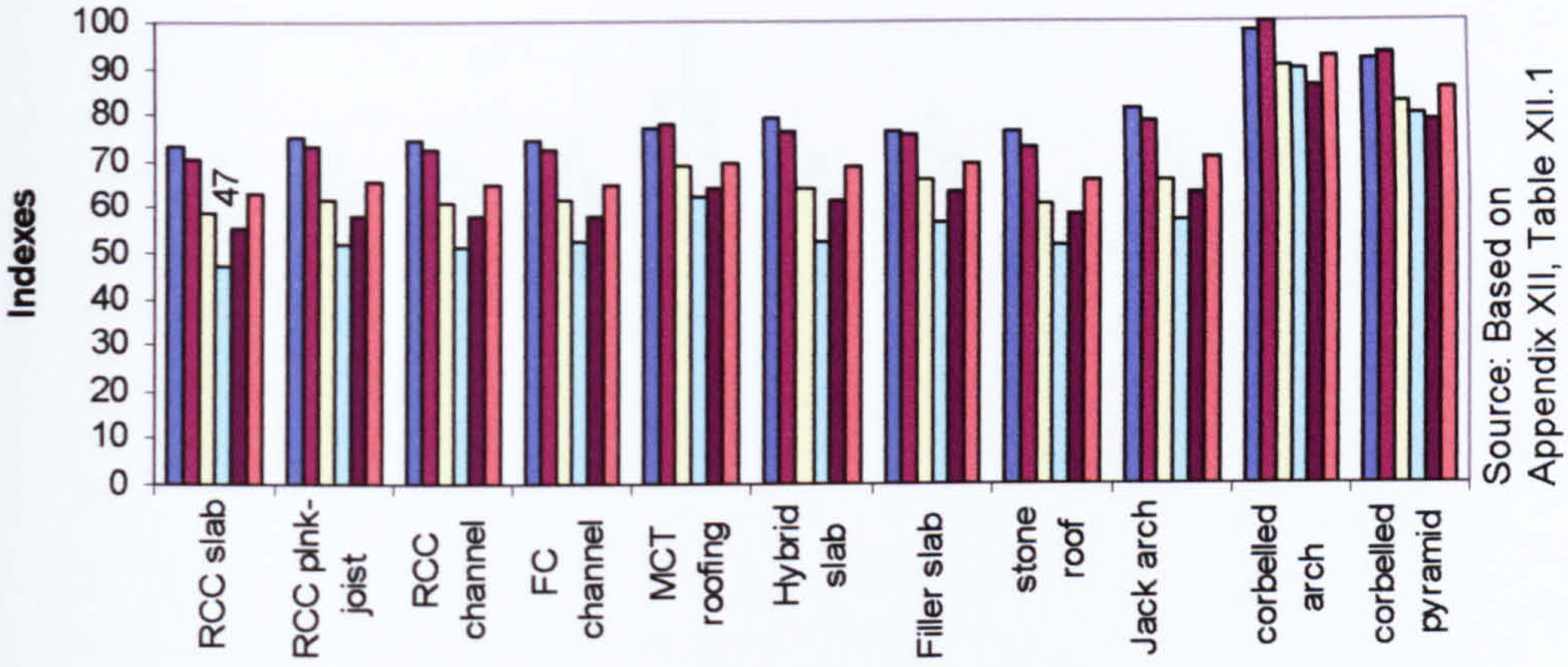
It may be reiterated that Figure 12-1 and Figure 12-2 suggest that the weighting of 128 may be accepted since, from that point onwards, the curves tend to become parallel to the X-axis. Therefore, the following sections will demonstrate the patterns of indexes by adopting 128 as the weight for each of the nine parameters. The group weightings have been assumed constant at 1. Assuming that all the weights are equal to 1, as shown below, the indexes of the 66 combinations have been shown in Figure 12-3.

Figure 12-3 The final **life cycle** indexes based on all 9 weights equal to 1



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-4 The final indexes of **new construction** based on all 9 weights equal to 1.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

The charts shown in Figure 12-3 and Figure 12-4 are based on calculations by assuming that the weightings of all the parameters are equal to 1. Both the charts show that the combination of corbelled arch roof with rat-trap masonry is the best choice. The lowest index is scored by the reinforced cement concrete roof with interlocking cement stabilised mud block wall for both new (47) and life cycle (60) impacts.

12.3.1 Unit Cost

<u>WEIGHTING OF UNIT COST = 128 , OTHERS =1</u>

Figure 12-5 The final **life cycle** indexes based on weighting of **unit cost** equal to 128 and 1 for each of the remaining parameters.

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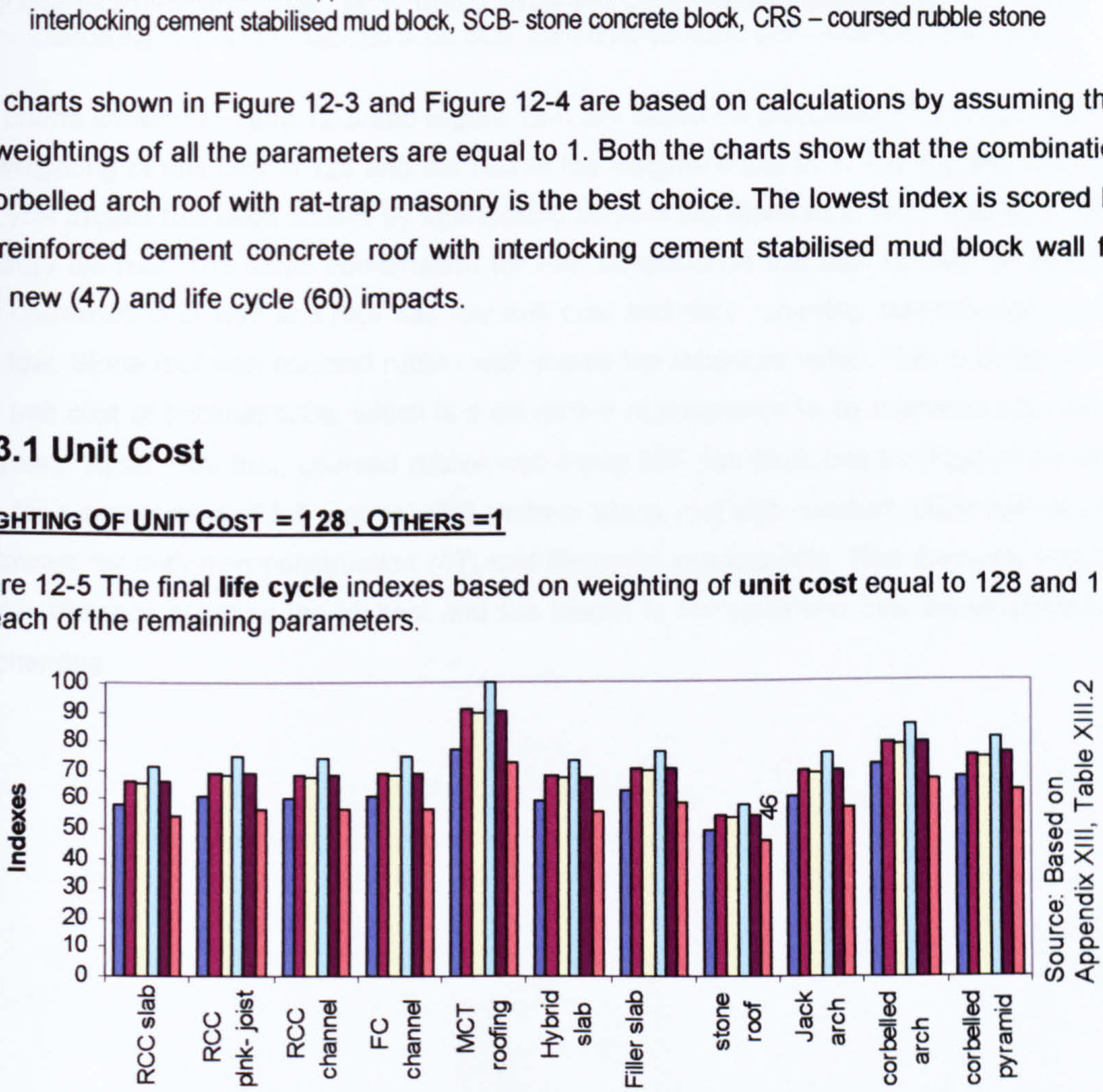
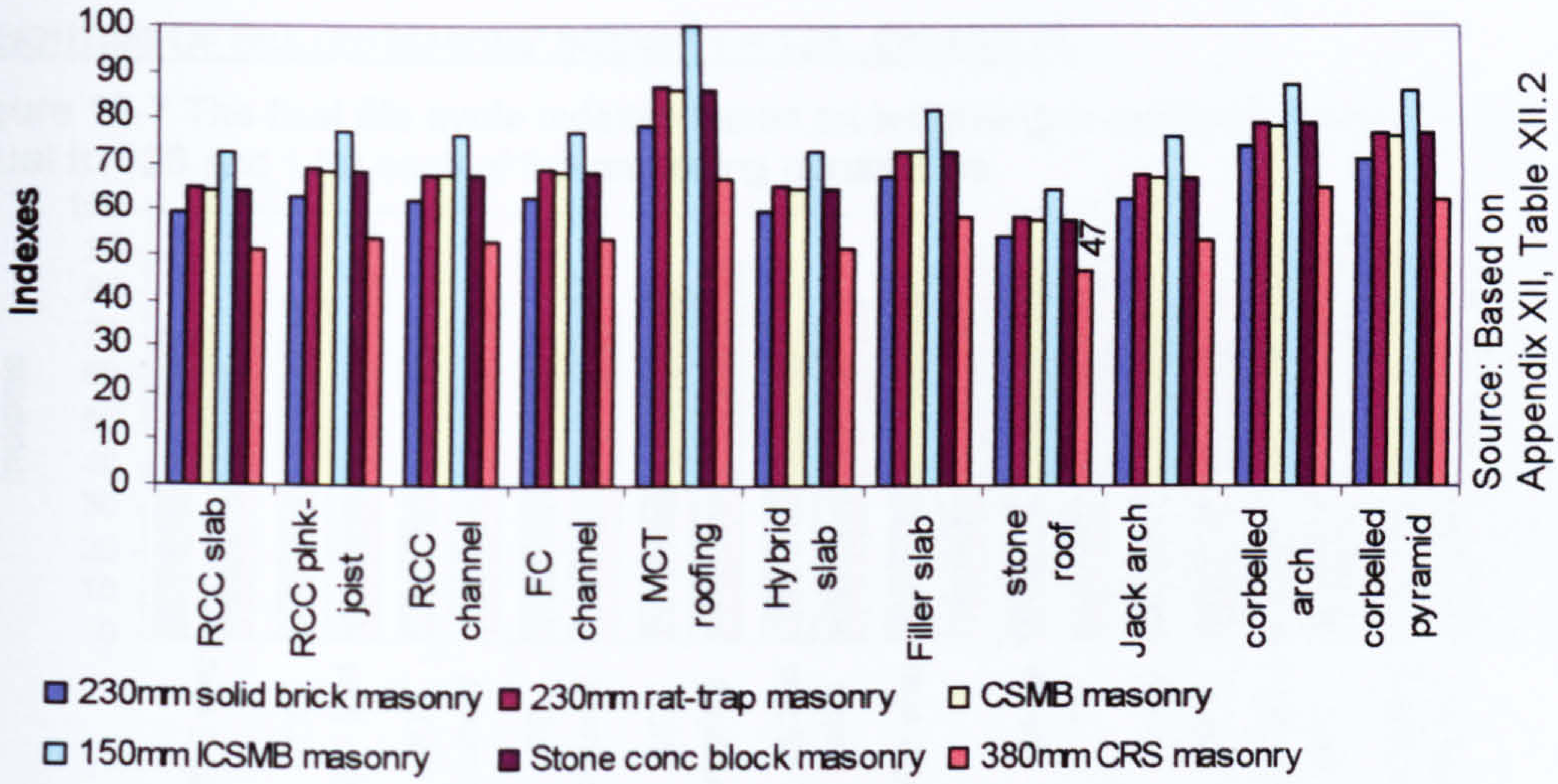


RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-6 The final indexes of **new construction** based on weighting of **unit cost** equal to 128 and 1 for each of the remaining parameters.



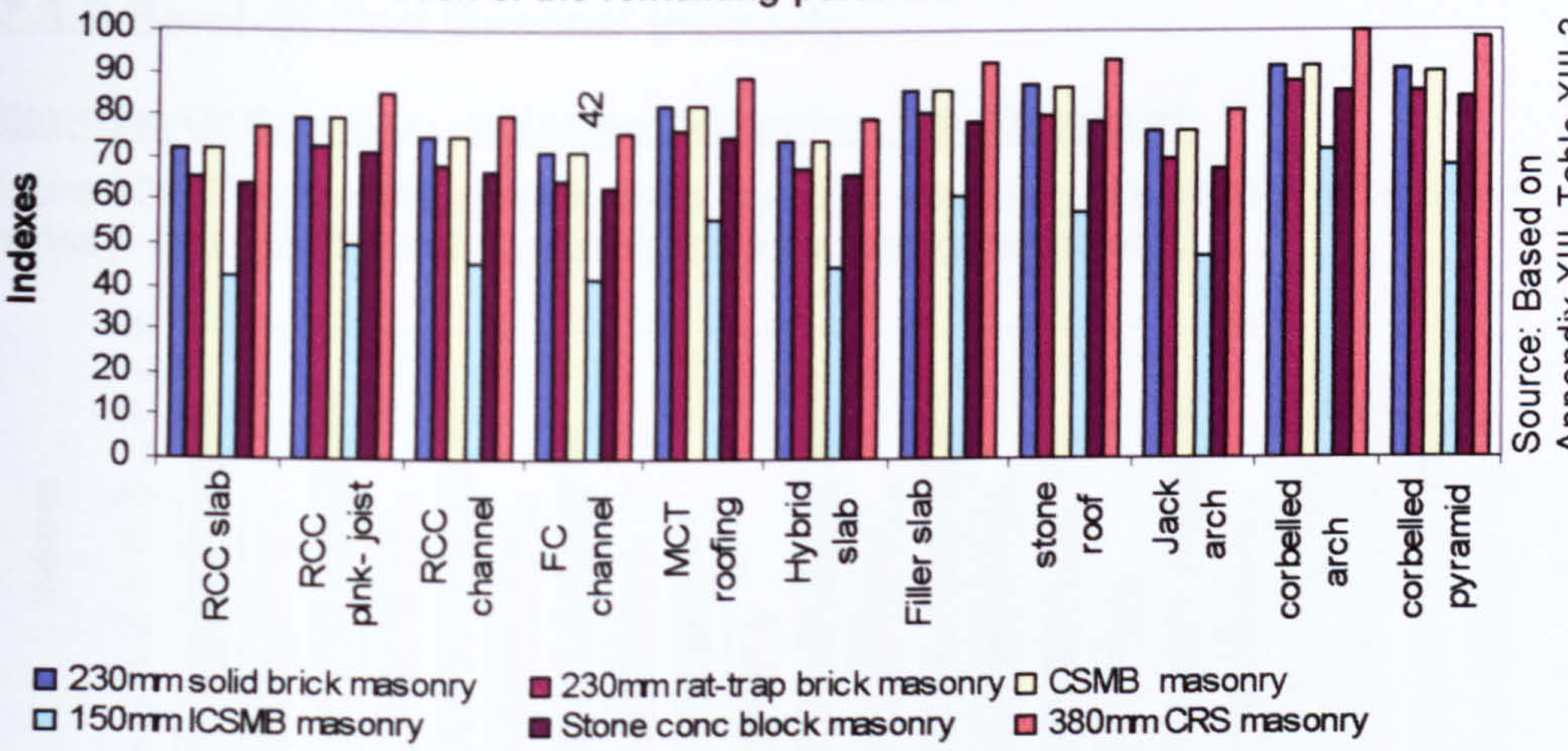
RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

The charts shown in Figure 12-5 and Figure 12-6 are based on calculations by assuming that the weighting of unit cost is 128 and the rest of the weights equal to 1. The highest index for life cycle impact has been scored by interlocking cement stabilised mud block wall with micro concrete tile roof. The same combination for new construction has also scored the highest. This combination of wall and roof has low unit cost and their recurring maintenance cost is also low. Stone roof with coursed rubble wall scores the minimum index. This is owing to the high unit cost of brickbat coba, which is a corrective maintenance to be repeated after every ten years. Apart from that, coursed rubble wall being 380 mm thick had the highest covered area for a carpet area of 5.5 metres x 5.5 metres. Stone roof with coursed rubble wall scores the lowest for both new construction (47) and life cycle impacts (46). This indicates that the relative distance between the highest and the lowest in life cycle and new construction has not changed.

12.3.2 Skilled Masons' Intensity

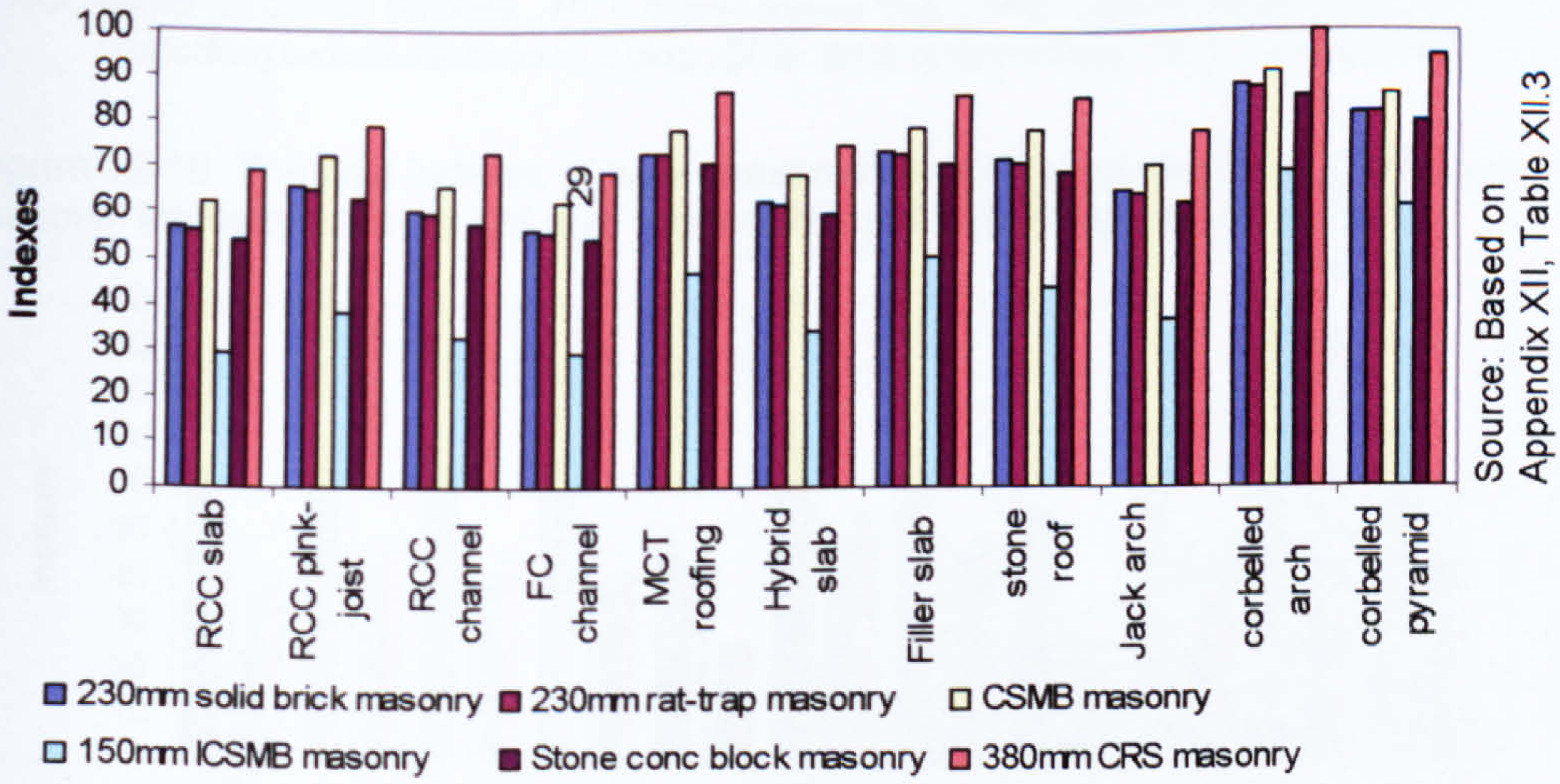
Weighting Of Skilled Masons' Intensity = 128 , Others =1

Figure 12-7 The final **life cycle** indexes based on weighting of **skilled masons'** intensity equal to 128 and 1 for each of the remaining parameters.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-8 The final indexes of **new construction** based on weighting of **skilled masons'** intensity equal to 128 and 1 for each of the remaining parameters.



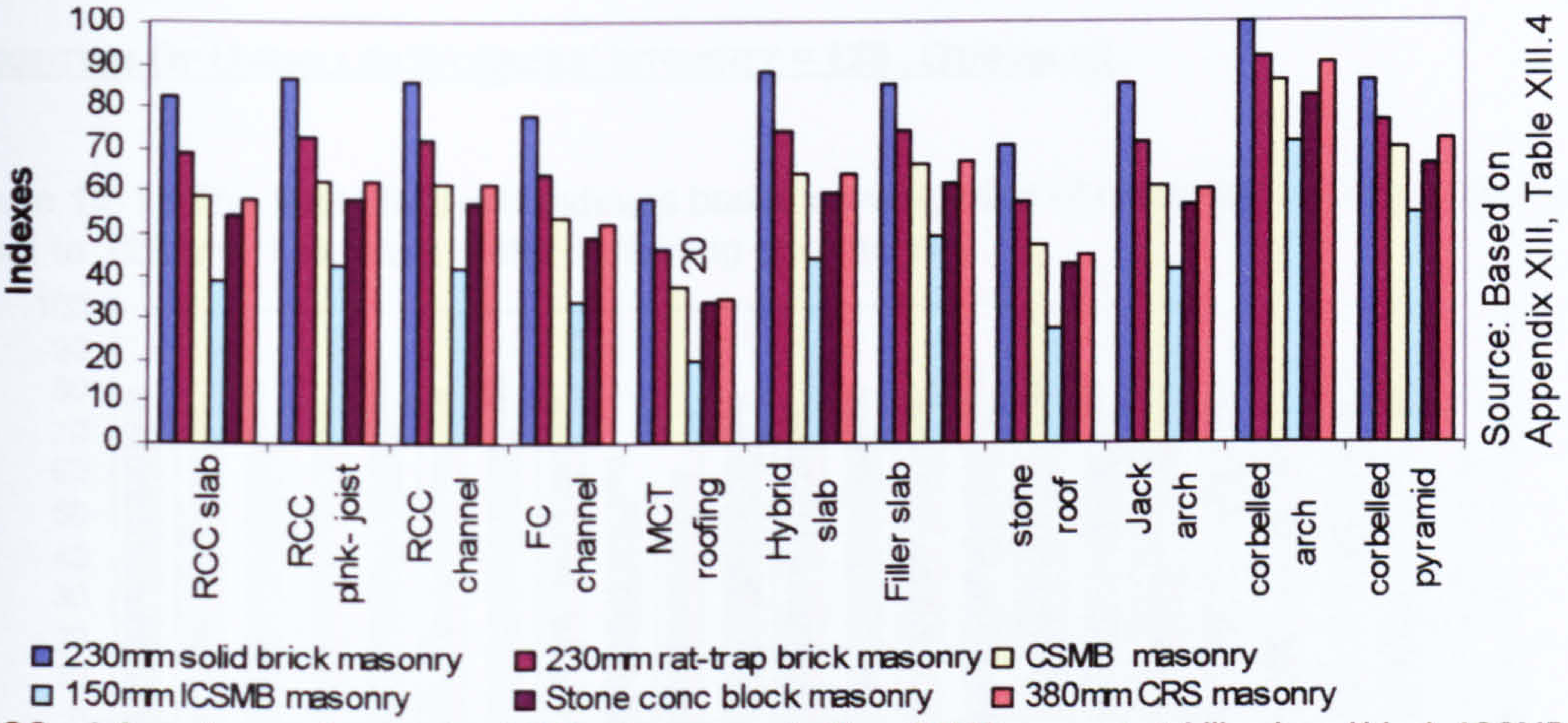
RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

The charts shown in Figure 12-7 and Figure 12-8 are based on calculations by assuming that the weighting of skilled masons' intensity is 128 and the rest of the weights equal to 1. The combination of coursed rubble stone wall with corbelled brick arch roof scored the highest index and the lowest index is obtained by ferrocement channel roof with interlocking block wall. Coursed rubble stone wall with corbelled brick pyramid is also very close to the highest score. The wall and roof that scored the highest is owing to the high skilled mason intensity of coursed rubble wall and brick-intensive roof both for new construction and over the whole life. It may be noted that interlocking block wall and ferrocement roof have low intensity of skilled mason. The combinations scoring the highest and the lowest indexes of the life cycle and new construction did not change. The lowest score of 29 for new construction has increased to 42 for the life cycle impact of interlocking block wall with ferrocement roof.

12.3.3 Semi-Skilled Masons' Intensity

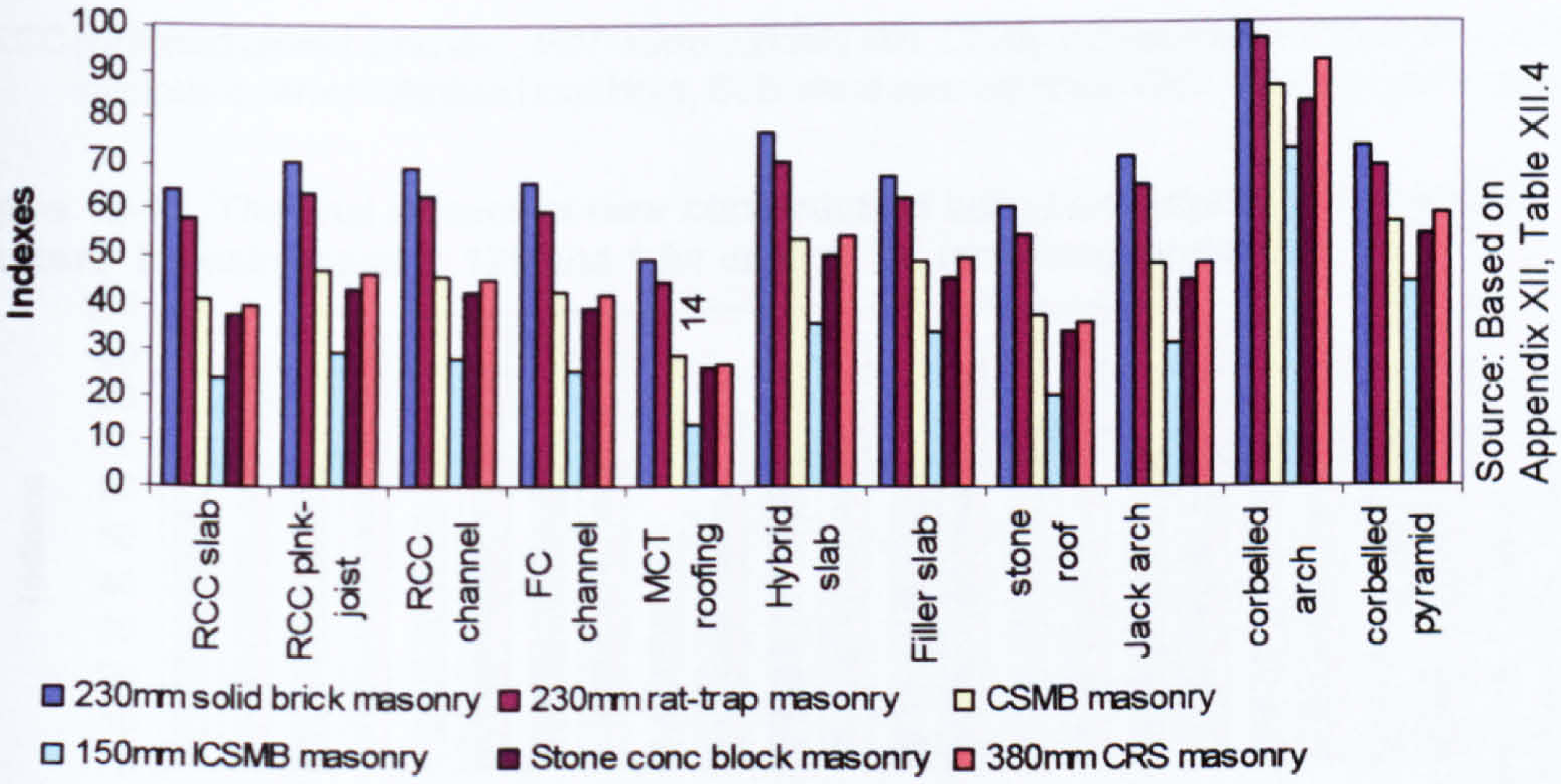
<u>**WEIGHTING OF SEMI-SKILLED MASONS' INTENSITY = 128 , OTHERS =1**</u>

_Figure 12-9 The final **life cycle** indexes based on weighting of **semi-skilled** masons' intensity equal to 128 and 1 for each of the remaining parameters.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-10 The final indexes of **new construction** based on weighting of **semi-skilled** masons' intensity equal to 128 and 1 for each of the remaining parameters.



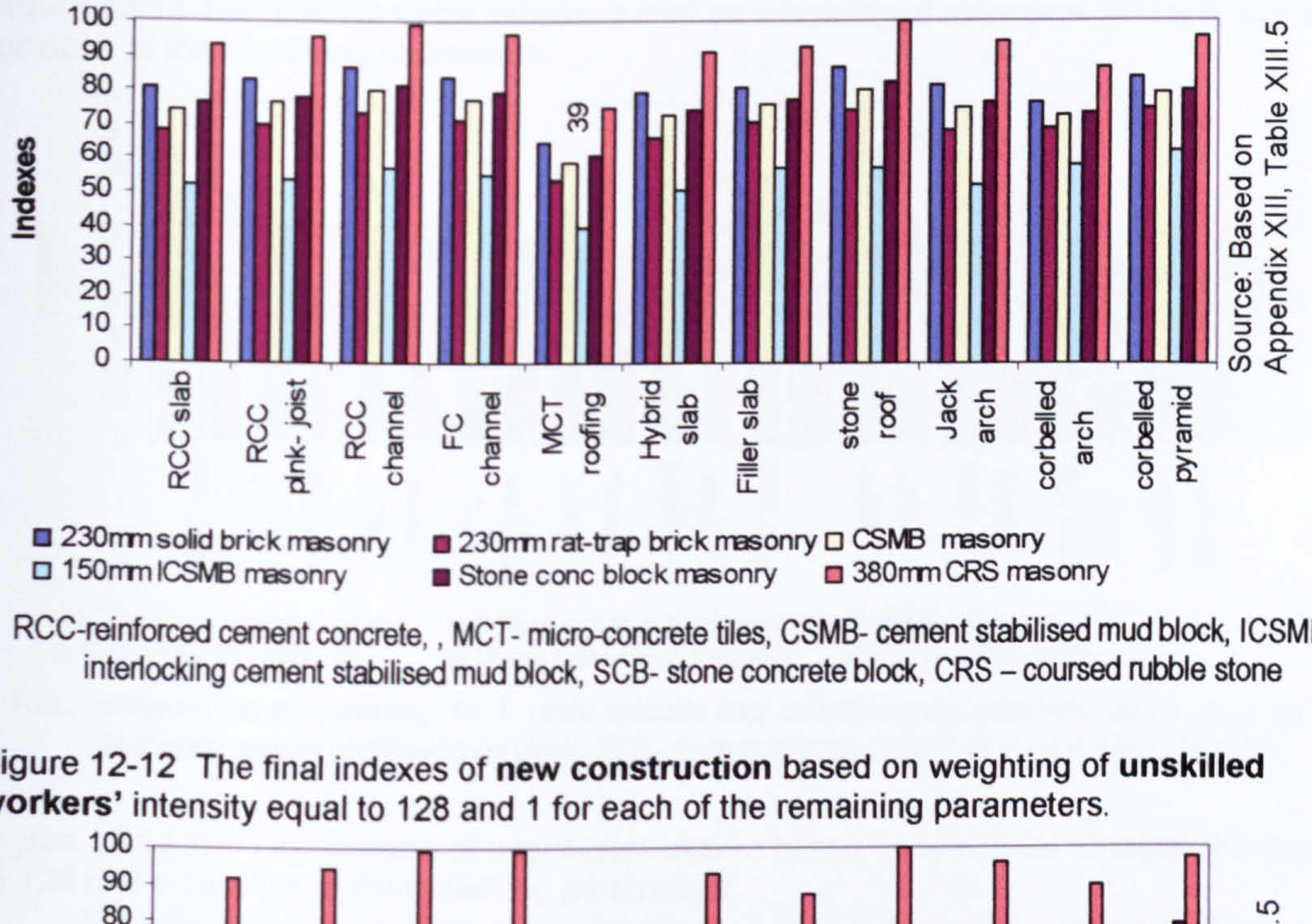
RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

The charts shown in Figure 12-9 and Figure 12-10 are based on calculations by assuming that the weighting of semi-skilled masons' intensity is 128 and the rest of the weights equal to 1. The combination of 230 mm thick solid brick wall with corbelled brick arch roof has scored the highest index and the lowest index is obtained by micro-concrete tile roofing with interlocking block wall. The figures show that the brick-intensive walls have high indexes. The walling and roofing combination scoring the highest and the lowest indexes of the life cycle and new construction did not change. The life cycle employment opportunities of the brick-based systems have high intensity of semi-skilled masons. The increase in the lowest index from 14 to 20 indicates that micro-concrete tile roofing with interlocking block wall will perform relatively better over time compared to the combination with highest score.

12.3.4 Unskilled Workers' Intensity

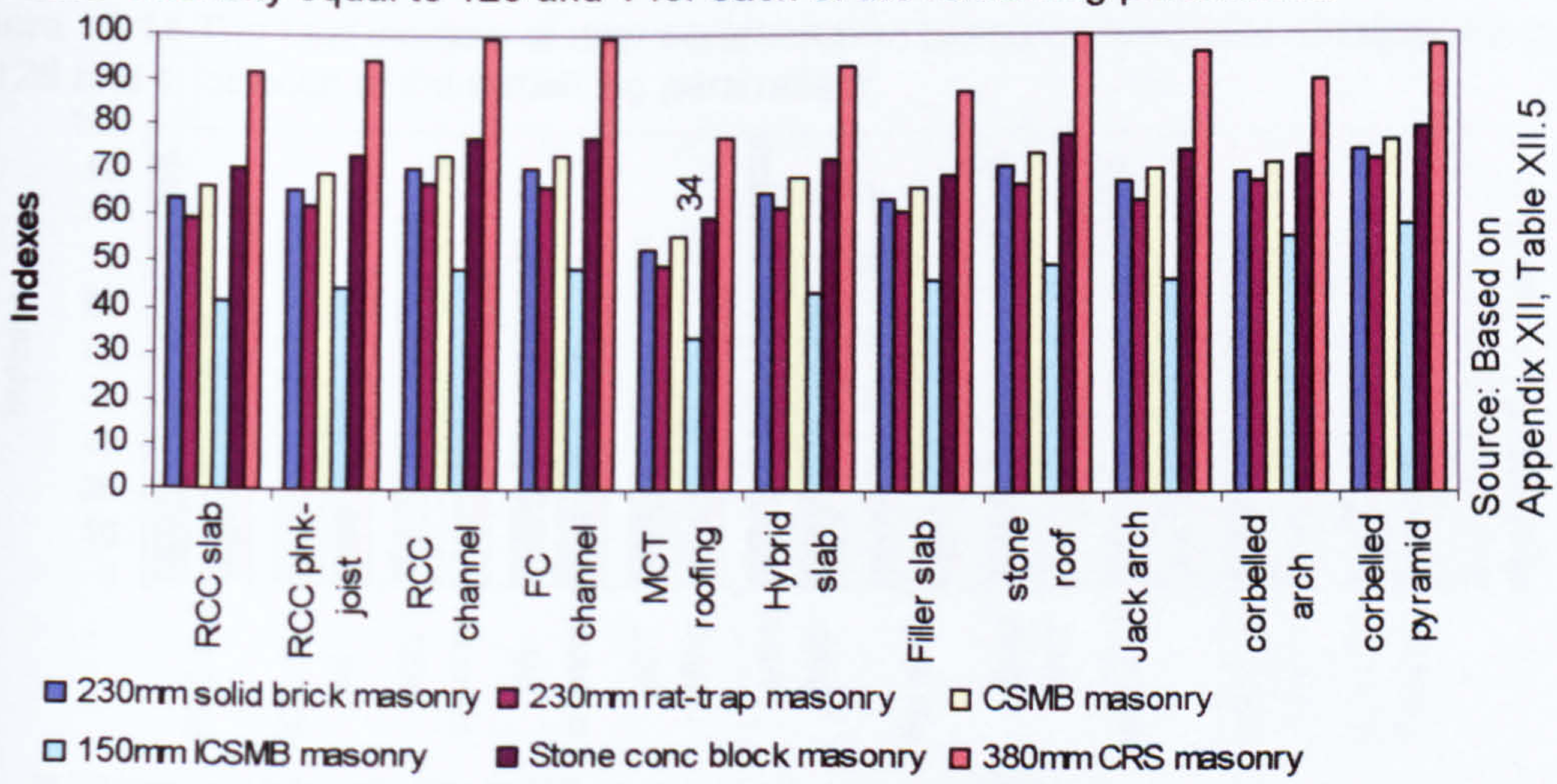
WEIGHTING OF UNSKILLED WORKERS' INTENSITY = 128 , OTHERS =1

Figure 12-11 The final **life cycle** indexes based on weighting of **unskilled workers'** intensity equal to 128 and 1 for each of the remaining parameters.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-12 The final indexes of **new construction** based on weighting of **unskilled workers'** intensity equal to 128 and 1 for each of the remaining parameters.



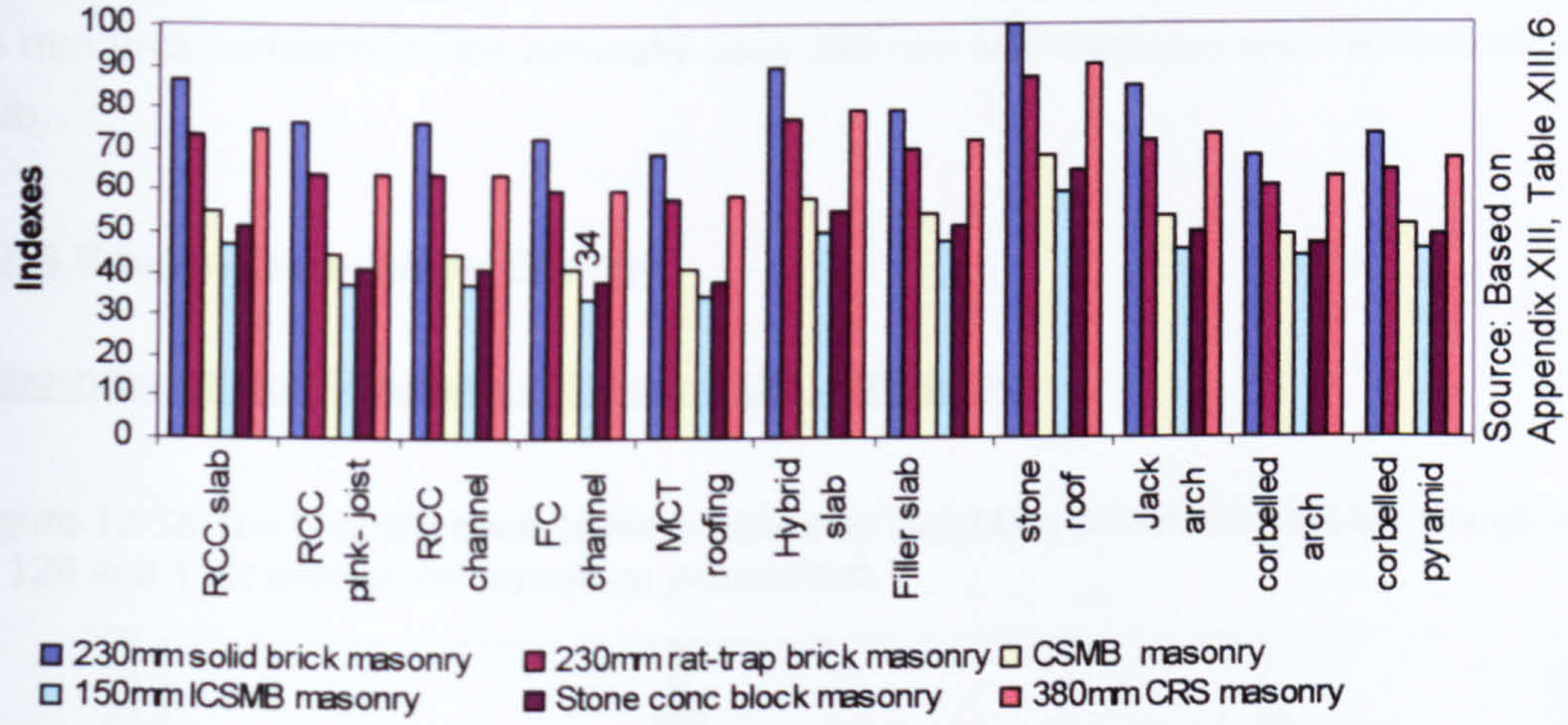
RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

The charts shown in Figure 12-11 and Figure 12-12 are based on calculations by assuming that the weighting of unskilled masons' intensity is 128 and the rest of the weights equal to 1. The combination of coursed rubble wall with stone roof scores 100. However, nine out of eleven roofing systems with coursed rubble wall score more than 90. The minimum index is scored by interlocking block wall with micro-concrete tile roofing. The maximum and minimum indexes remain the same for both new construction and life cycle. In such a situation, any of the nine combinations with coursed rubble stone wall may be suitable and hence, the decision makers have to look at the other parameters to choose the most appropriate combination in a context.

12.3.5 Retention

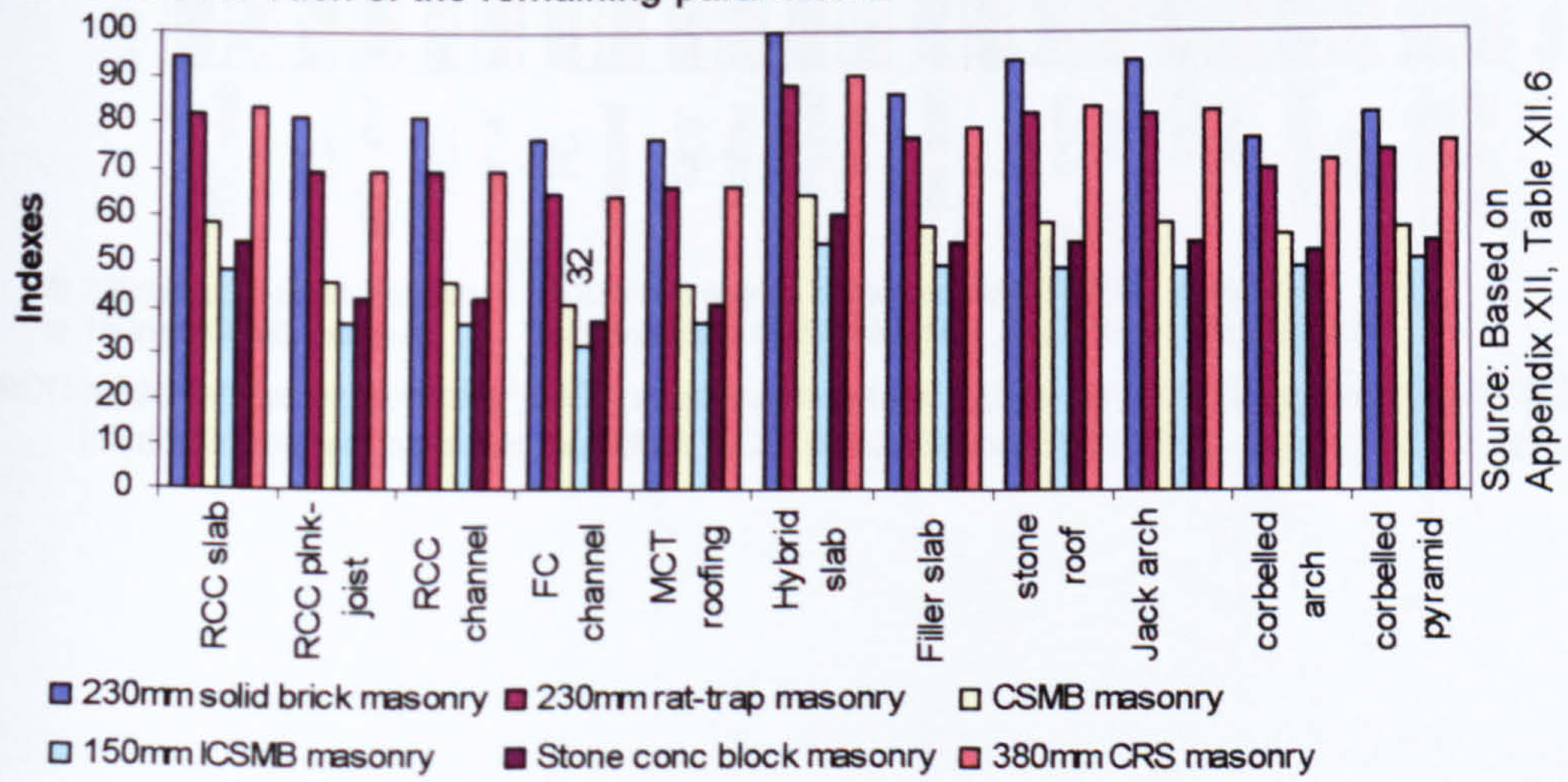
<u>**WEIGHTING OF RETENTION = 128 , OTHERS =1**</u>

Figure 12-13 The final **life cycle** indexes based on weighting of **retention** equal to 128 and 1 for each of the remaining parameters.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-14 The final indexes of **new construction** based on weighting of **retention** equal to 128 and 1 for each of the remaining parameters.



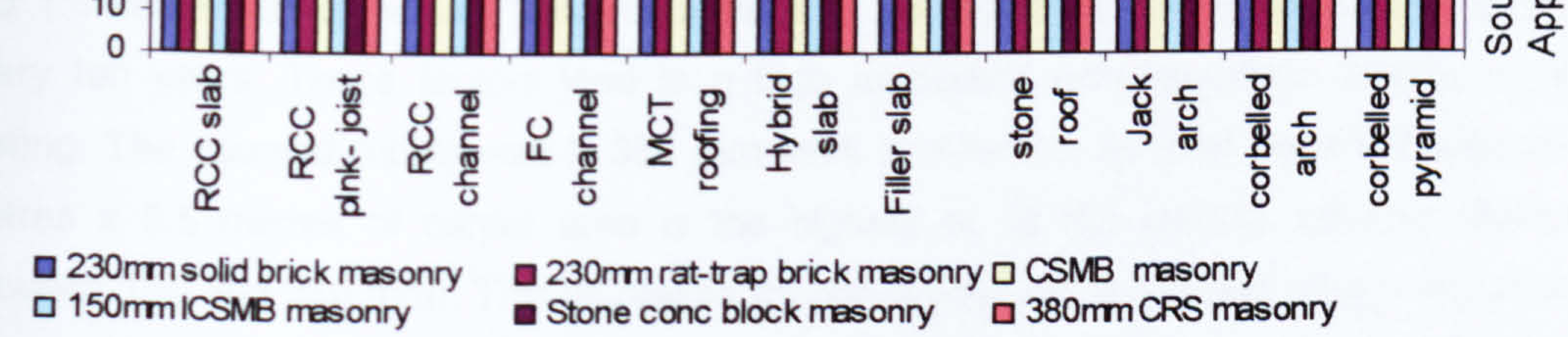
RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-13 and Figure 12-14 show the indexes of the 66 combinations of walling and roofing technologies adopted for constructing 1,068 one classroom units. The charts are based on calculations by assuming that the weighting of retention is 128 and the rest of the weights equal to 1. All the roofing systems with brick-intensive walls and coursed rubble wall score high indexes since brick and stone were locally manufactured and quarried in Ranga Reddy district. The life cycle score of the stone roof in combination with 230 mm solid brick wall is 100 since both the wall and the roof waterproofing treatment are brick-intensive. It is important to note that the highest score from the point of new construction was obtained by the same walling systems (solid brick) with hybrid slab. The main reason for this change is the use of bricks in brickbat coba as roof treatment on stone roof, which retains more money within the district since brick is local. Whereas, the impervious waterproofing coat on hybrid slab, being cement-intensive, retains less than the stone roof. Interlocking blocks with ferrocement channel scores the lowest since both of them have low consumption of materials. It may be noted that interlocking block wall is 150 mm thick and ferrocement channel is 25 mm thick compared to the generally used 230 mm wall thickness and 100 mm thick roof slab.

12.3.6 Non-Renewable Energy

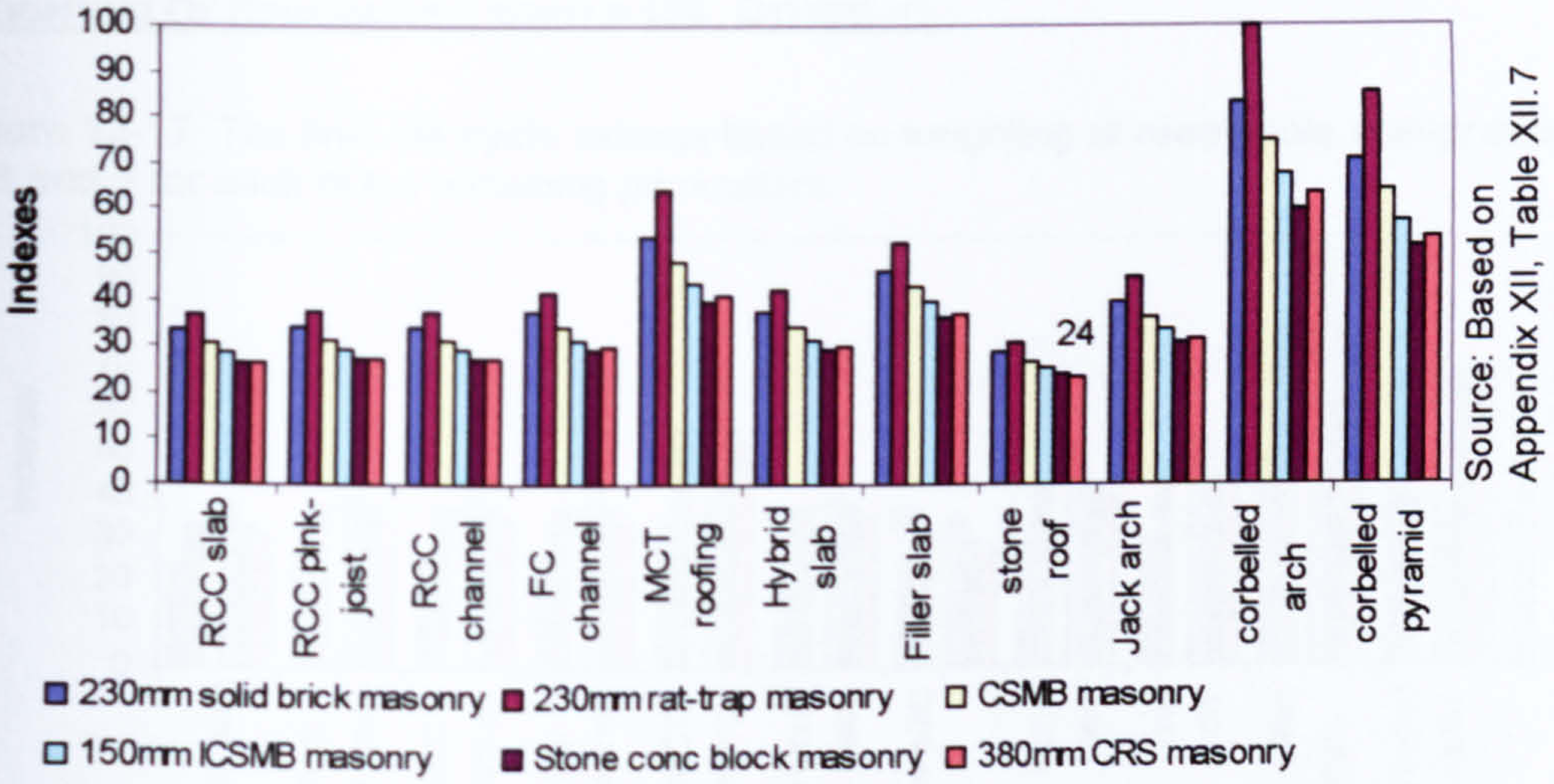
<u>WEIGHTING OF NON-RENEWABLE ENERGY = 128 , OTHERS =1</u>

Figure 12-15 The final **life cycle** indexes based on weighting of **non-renewable** energy equal to 128 and 1 for each of the remaining parameters.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-16 The final indexes for **new construction** based on weighting of **non-renewable energy** equal to 128 and 1 for each of the remaining parameters



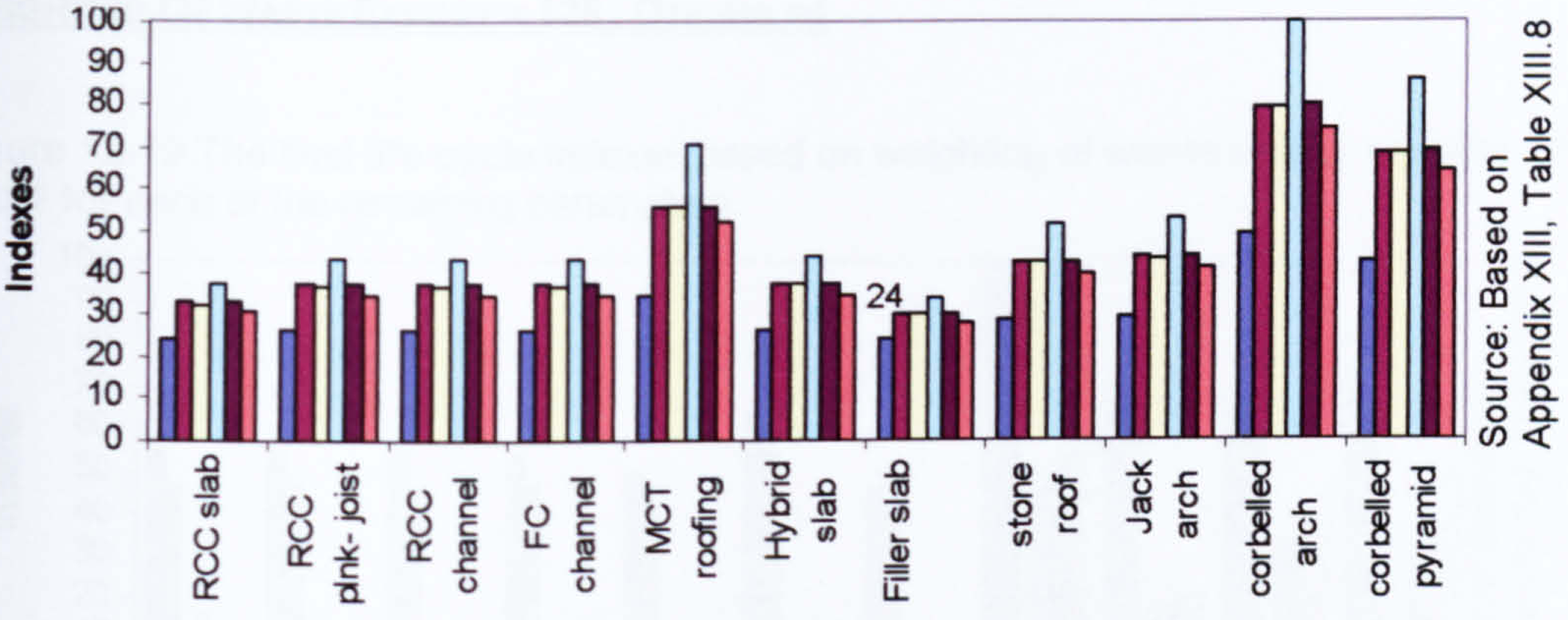
RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

With 128 as the weighting of non-renewable energy, the rat-trap wall with corbelled brick arch roofing has the highest score in new construction (Figure 12-16). It is important to note that brick-intensive roofs were efficient in terms of embodied non-renewable energy since rice husk was used for brick production in Ranga Reddy district. In Rat-trap wall, 80 bricks per cubic metre of masonry are saved compared to solid brick wall. Therefore, the cement content of this walling technology is also low, which reduces its embodied non-renewable energy. In corbelled arch roof, projection of each course of bricks from the previous one reduces the mortar volume in the masonry. This reduces its cement consumption than solid brick work. These are the reasons for the highest score obtained by rat-trap wall with corbelled brick arch roofing. Stone roof with coursed rubble wall scores the lowest in life cycle and new construction as well. A stone roof uses pre-cast reinforced cement concrete ribs, which is steel and cement-intensive. Brickbat coba as waterproofing on stone roof uses 1:4 and 1:3 cement-sand mortar. This treatment is to be re-laid as corrective maintenance after every ten years. These factors lead to a high embodied non-renewable energy of stone roofing. The coursed rubble wall is 380 mm thick and hence, its total elevation area for 5.5 metres x 5.5 metres of carpet area is the highest of all the walling systems (thickness between 150 and 230 mm). This increased its non-renewable embodied energy which is the main reason why all the roofing systems with coursed rubble stone wall scored low. The scores of the roofs with stone concrete block wall are also low since the blocks are cement-intensive. It is important to note that the highest score for new construction is corbelled arch roof with rat-trap wall. In life cycle score, the best combination is rat-trap wall with micro-concrete tile roof (Figure 12-15). This change is owing to the recurring maintenance of the waterproofing treatment of corbelled arch roof which is cement-intensive. In comparison, micro-concrete tile roof does not require any water proofing and hence, it scored highly with rat-trap wall in life cycle.

12.3.7 Renewable Energy

<u>WEIGHTING OF RENEWABLE ENERGY = 128 , OTHERS =1</u>

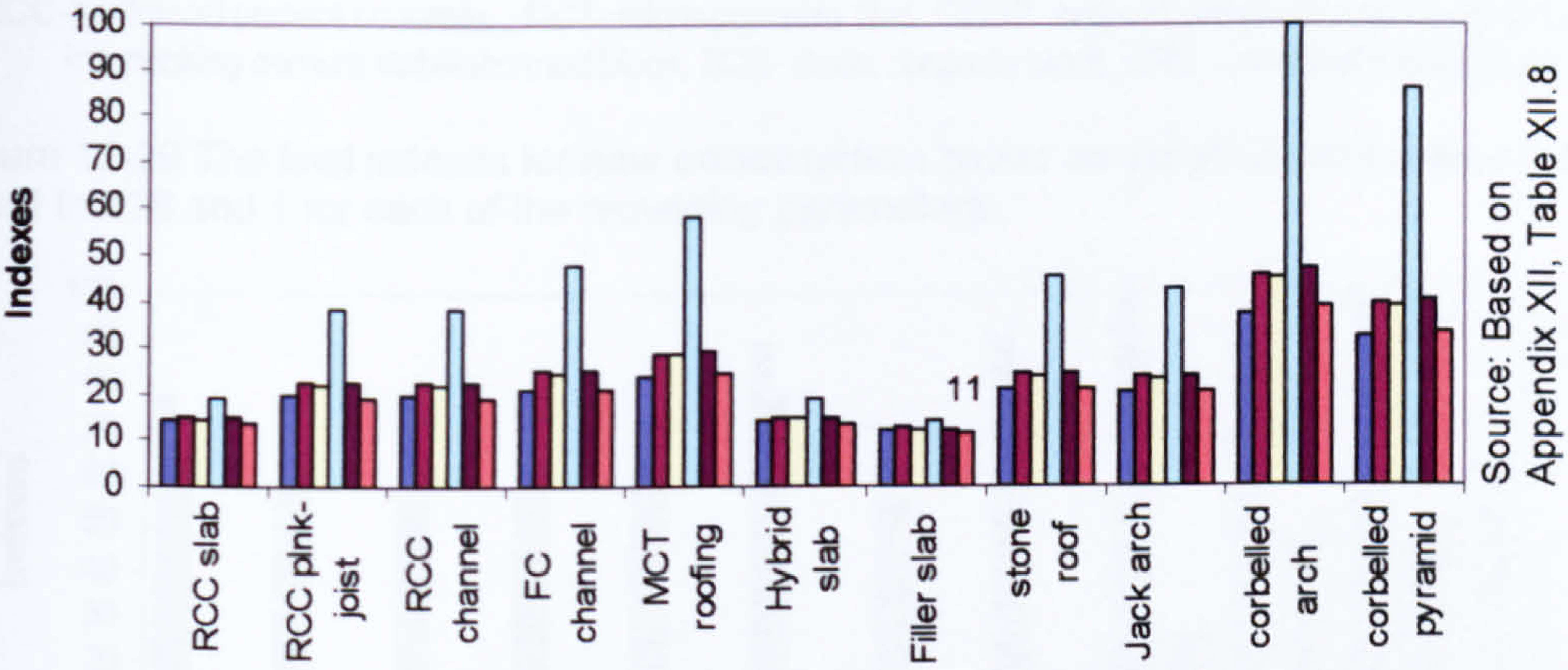
Figure 12-17 The final **life cycle** indexes based on weighting of **renewable** energy equal to 128 and 1 for each of the remaining parameters.



■ 230mm solid brick masonry ■ 230mm rat-trap brick masonry □ CSMB masonry
□ 150mm ICSMB masonry ■ Stone conc block masonry ■ 380mm CRS masonry

RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-18 The final indexes for **new construction** based on weighting of **renewable** energy equal to 128 and 1 for each of the remaining parameters.



■ 230mm solid brick masonry ■ 230mm rat-trap masonry □ CSMB masonry
□ 150mm ICSMB masonry ■ Stone conc block masonry ■ 380mm CRS masonry

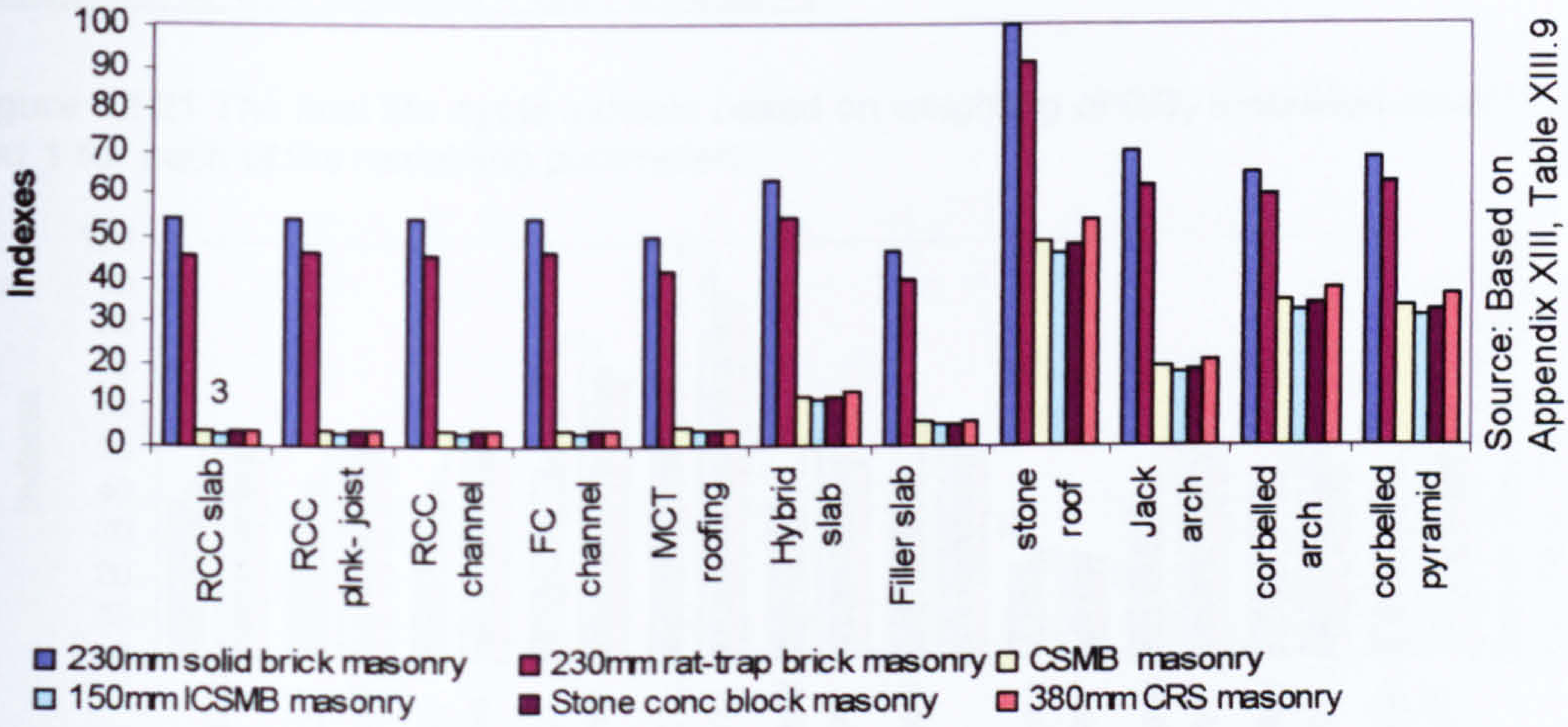
RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

While the highest life cycle score is obtained by interlocking cement stabilised mud block wall with corbelled arch, the least one is obtained by solid brick wall with filler slab (Figure 12-17). Corbelled brick roofs are superior to the rest of the roofing systems in terms of renewable energy since the latter require wooden shuttering and the former are constructed without it. It may be noted that the least score in new construction is obtained by coursed rubble wall and filler slab. The main reason for the coursed rubble wall being superior to solid brick wall in life cycle is the latter's requirement of wooden scaffolding for external painting after every four years, which is not required for the former. It may be noted that the lowest score of new construction (11) has increased in life cycle impact (24) indicating that the difference between the maximum and minimum scores in life cycle impact has reduced.

12.3.8 Waste Energy

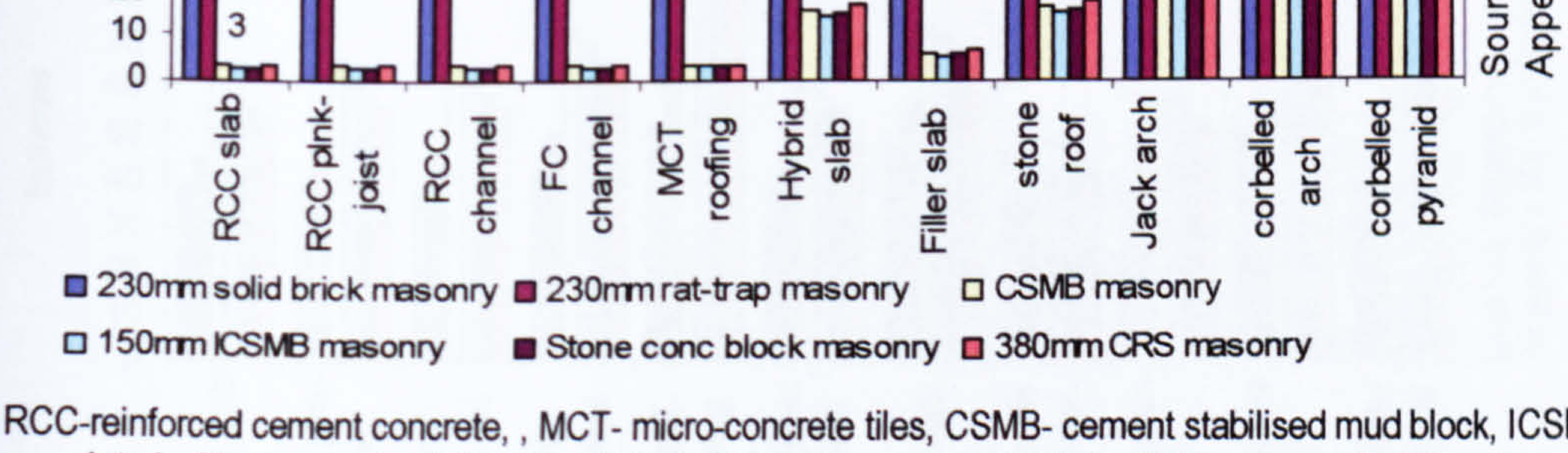
<u>**WEIGHTING OF WASTE ENERGY = 128 , OTHERS =1**</u>

Figure 12-19 The final **life cycle** indexes based on weighting of **waste** energy equal to 128 and 1 for each of the remaining parameters.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-20 The final indexes for **new construction** based on weighting of **waste** energy equal to 128 and 1 for each of the remaining parameters.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

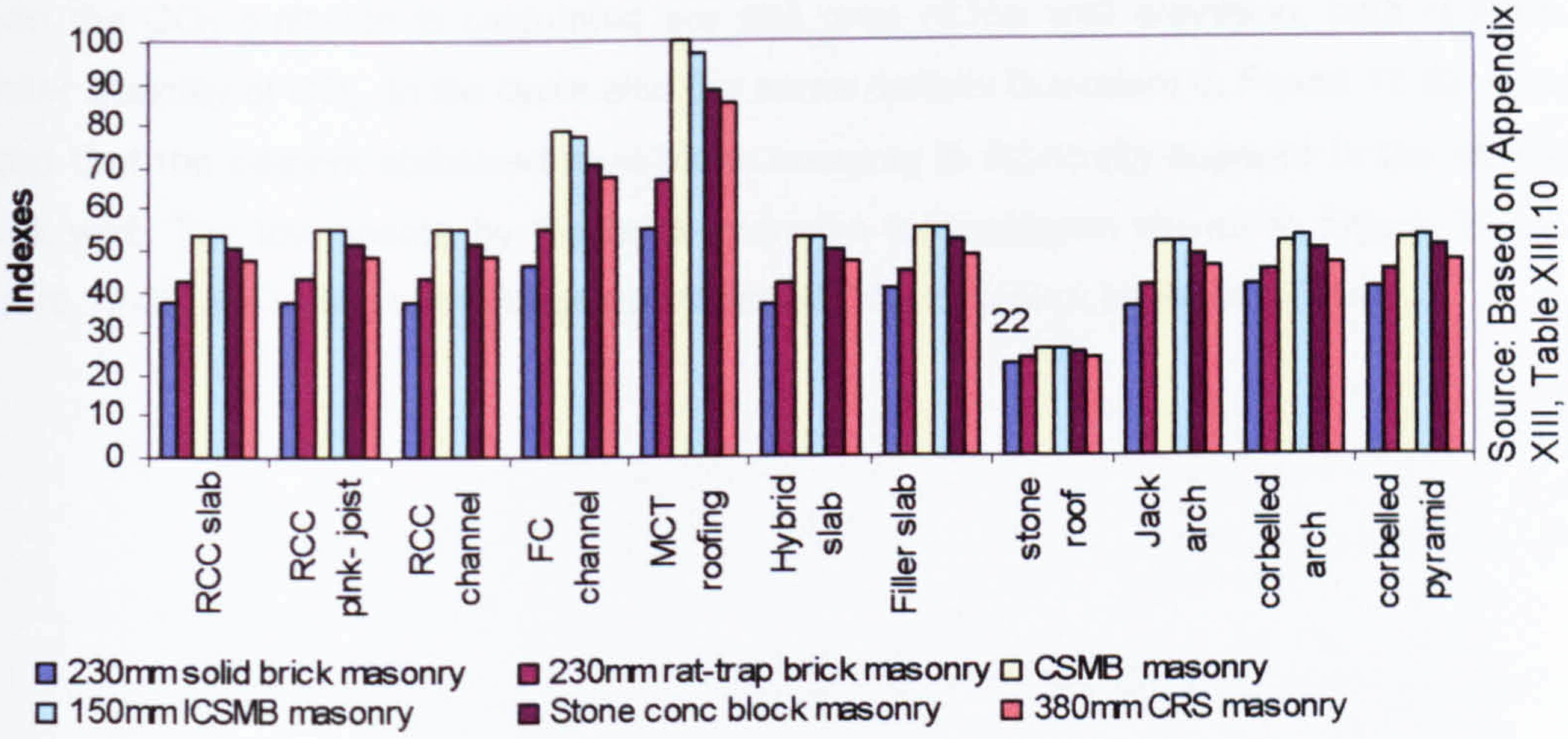
Assuming 128 as the weighting of embodied energy from agriculture waste, the brick-intensive systems score very highly both on life cycle and new construction. The above Figure 12-19 and Figure 12-20 show that jack-arch roof with solid brick wall as the best option for new construction is superseded by the same walling system with stone roof in life cycle.

The main reason for this is the use of different roof waterproofing systems which are to be re-laid as corrective maintenance. Jack-arch has a cement-intensive waterproofing and the stone roof uses brick and cement-sand (brickbat coba) as a roof treatment. The input of brick in the brickbat coba as waterproofing on the stone roof after every ten years increased its score in life cycle because brick production in Ranga Reddy was rice husk-based.

12.3.9 CO_2 Emission

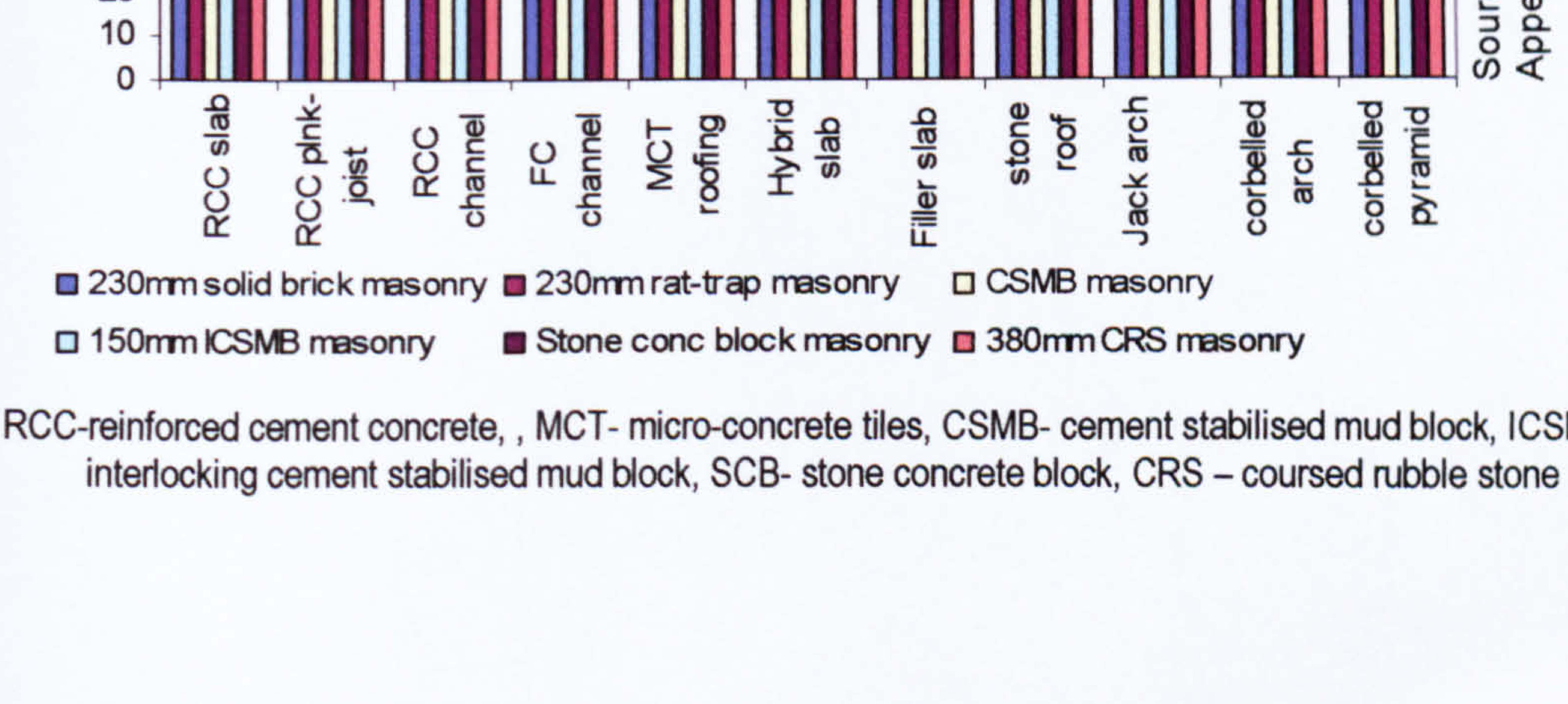
<u>**WEIGHTING OF CO_2 EMISSION = 128 , OTHERS =1**</u>

Figure 12-21 The final **life cycle** indexes based on weighting of **CO_2 emission** equal to 128 and 1 for each of the remaining parameters.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

Figure 12-22 The final indexes for **new construction** based on weighting of **CO_2 emission** equal to 128 and 1 for each of the remaining parameters.



RCC-reinforced cement concrete, , MCT- micro-concrete tiles, CSMB- cement stabilised mud block, ICSMB – interlocking cement stabilised mud block, SCB- stone concrete block, CRS – coursed rubble stone

The charts shown in Figure 12-21 and Figure 12-22 are based on calculations by assuming that the weighting of CO_2 emission is 128 and the rest of the weights equal to 1. The most CO_2 emission friendly combination of wall and roof is micro concrete tile roof with cement stabilised mud block wall (for both life cycle and new). Most of the walling technologies in combination with micro concrete tile roof have scored highly in life cycle and new construction. Although micro concrete tiles are cement-intensive, their thinness reduces the overall consumption of this CO_2 emission-intensive material. The indexes of the roofs in combination with cement stabilised mud block for new construction are very close to that of the combinations with interlocking block masonry. While interlocking blocks are cement-intensive (10% stabilisation) the thickness of wall made out of this is 150 mm. The cement stabilised mud block with 5% cement stabilisation makes a 230 mm thick wall. Therefore, when the CO_2 emission is calculated per unit area of the wall elevation, both of them emit similar quantity of CO_2. In life cycle also the same pattern is evident in Figure 12-22. It is to be noted that the cement stabilised mud block masonry is thermally superior to the interlocking block wall. The low scores by the brick-intensive technologies shown in Figure 12-21 and Figure 12-22 are owing to the large quantities of CO_2 emission by these systems.

12.4 SUMMARY OF OBSERVATIONS

Table 12.3 The best combinations of walling and roofing technologies according to the high weights assigned to the different parameters.

Life cycle impacts		
Weightings	**Walling**	**Roofing**
All weights equal to 1	230 mm rat-trap wall	Corbelled brick arch
SOCIO-ECONOMIC PARAMETERS		
Unit cost =128	Interlocking cement stabilised mud block	Micro concrete tile on steel and timber under-structure
Skilled lab intensity = 128	380 mm coursed rubble stone	Corbelled brick arch
Semi-skilled lab intensity=128	230 mm solid brick wall	Corbelled brick arch
Unskilled lab intensity=128	380 mm coursed rubble stone	Stone slabs on pre-cast reinforced cement concrete ribs
Retained =128	230 mm solid brick wall	Stone slabs on pre-cast reinforced cement concrete ribs
ENVIRONMENTAL PARAMETERS		
Non-renewable energy consumption=128	230 mm rat-trap wall	Micro concrete tile on steel and timber under-structure
Renewable energy consumption=128	Interlocking cement stabilised mud block	Corbelled brick arch
Agriculture waste consumption=128	230 mm solid brick wall	Stone slabs on pre-cast reinforced cement concrete ribs
Emission of CO_2 =128	Cement stabilised mud block wall	Micro concrete tile on steel and timber under-structure

Source: Based on Figure 12-3 to Figure 12-22

Table 12.3 shows the summary of the indexes in the context of Ranga Reddy. It shows the best combinations of walling and roofing systems, if one has to construct 1,068 one classroom units under different socio-economic and environmental situations. The first column of Table 12.3 shows the weightings assigned to the nine socio-economic and environmental parameters. The group weightings, as mentioned before, have been assumed to be 1.

The most noticeable pattern of the Table 12.3 is that there is only one repetition of the combinations, which is 230 mm solid brick wall with stone slab roof under the high weightings of retention and embodied waste energy (shaded boxes). The rest of the combinations are very specific to the situation. For example, under equal weightings, 230 mm rat-trap wall with corbelled arch roof is the best choice. However, in a situation where unit cost is the most important issue, micro-concrete tile roof with interlocking block walls are far superior to the rest of the options.

Table 12.4 Domain of the best options of walling and roofing as best options in the context of Ranga Reddy.

WALLING / ROOFING	230 mm solid brick wall	230 mm trap bonded brick wall	230 mm cement stabilised mud block wall	150 mm interlocking cement stabilised mud block wall	380 mm coursed rubble stone masonry wall
Micro concrete tile roof with steel and timber under-structure		6 Non renewable energy	9 emission of CO_2	1 unit cost	
Stone roofing on pre-cast reinforced cement concrete joists	2 retention 8 waste				5 unskilled workers
Brick corbel arch	4 semi skilled	0 all weights equal		7 renewable energy	3 skilled

Source: Based on Figure 12-3 to Figure 12-22

The above table shows the best combinations of walls and roofs when a weight of 128 is applied on each parameter at a time while keeping the rest eight equal to "1". It may be noted that, the most desirable solution will depend upon the nine weights generated in a real situation by involving the beneficiaries, subject specialists, decision makers, national and international statues, regulations, etc. However, the following Inferences, in the domain of this dissertation, may be drawn from Table 12.4 in the context of Ranga Reddy district.

- As mentioned before, corbelled arch and rattrap wall, i.e., brick intensive is the best combination in Ranga Reddy with all weights being equal.

- Repetition of a particular walling and roofing combination only once (2nd column and 3rd row in Table 12.4) under different weights suggest that the outputs of the model are very much dependent upon the weights and the results are difficult to predict intuitively.

- By adopting the weights described above, three out of eleven roofing systems and five out of six walling systems have come out to be the sustainable options. Let us analyse this pattern to understand the root causes. Solid and rat trap bonded brick wall and brick corbel arch roof are primarily made of locally produced bricks based on local soil and rice husk as fuel, which is an agricultural waste. The cement stabilised mud block are based on local soil with low level (5%) of cement stabilisation. The coursed rubble stone is based on local stone. The stone roofing is based on Tandur stone in which embodied energy and CO_2 emission are very low. Apart from that it uses brick in the roof waterproofing, which is a local material.

Micro concrete tile roof is cement and steel-based, however, the consumptions of these two materials are low since it is a light weight roof and the tiles are very thin (8mm) compared to the other roofing systems. Similarly, although interlocking mud wall is cement based (10% stabilisation), the consumption of cement per unit wall area is low owing to its thickness of 150mm, which varies between 380mm and 200mm for other walling systems.

From the above discussion, it appears that the walling and roofing systems based on local materials or with low cement and steel consumption have scored highly in Ranga Reddy based on the weights described above. Therefore, solid brick wall, trap bonded wall, cement stabilised mud block wall, stone roofing and Brick corbel arch are suitable in the context of Ranga Reddy. Apart from being suitable options in Ranga Reddy, micro concrete tile roof and interlocking cement stabilised mud block wall would be suitable in other contexts where the climate is moderate since their thermal insulations are low.

From the Table 12.4, a decision maker can choose the combination of wall and roof depending upon which parameter with the highest weight is suitable to a context. For example, if the most important objective in Ranga Reddy were to reduce CO_2 emission, the decision maker would choose the combination of micro concrete tile roof and cement stabilised mud block wall.

Therefore, it appears that the impact assessment of the new construction (chapter 10) and life cycle (chapter 11), in terms of actual quantities, will enable decision makers to understand the grass-root level implications. Table 12.3 and Table 12.4, based on the indexes, will help one to choose the sustainable options in a context. However, the most sustainable solution could be determined if context specific weights are calculated by involving the beneficiaries, specialists, administrators, etc. following the methods/processes such as Brownfield Regeneration experience, Analytical Hierarchical Process, etc.

CHAPTER 13 : CONCLUSIONS

13.1. REVIEWING THE AIMS AND OBJECTIVES

It may be recalled that the dissertation had two aims. The first one was to provide an impact assessment tool for the decision makers to select sustainable building construction technologies in the context of social infrastructure development in rural India. The second aim was to demonstrate how to calculate the socio-economic and environmental impacts in a rural context through the use of different walling and roofing technologies.

This dissertation had five objectives. Let us first discuss how these objectives have been achieved. The first objective of this dissertation was to describe the Andhra Pradesh Primary Education Project and examine its efficacy as a base for developing an impact assessment tool. It is important to mention that the Andhra Pradesh data is an asset. As mentioned before, the school buildings were constructed and are ageing under uniform conditions. Therefore, the process of data collection is like Hammond's (1978) controlled trial as described by Tipple and Willis (1991). Therefore, the data on new construction and life cycle impacts are valuable and rare.

The data and experience of this project was documented meticulously. It is a three thousand page document that was written every evening between 1995-96 and 1999-2000. Based on that, in chapter 5 and 6, the impact of adopting different technologies on the socio-economy and environment (life cycle and new construction) has been examined in the context of Ranga Reddy district. These two chapters provide a detailed analysis of how architectural design, site conditions, construction technologies etc., could influence the socio-economic and environmental impacts at village level. Appendix VII to Appendix XI show the break-down of impacts at 16 sites in Ranga Reddy district. These examples provide a quantitative picture of what actually happens when buildings are constructed and then maintained.

Chapter 5 and 6 have shown that the experience of Andhra Pradesh Primary Education Project could be used as a base for developing an impact assessment tool. These experiences and the processes have been utilised to develop an impact assessment tool in chapter 7. Such a tool will help the decision makers to understand the implications of different construction technologies and enable them to make informed choices for social infrastructure planning. This may be particularly useful for the Government policy makers in India, who have been facing the challenge of supplying the basic minimum services to the citizens. Therefore, the objective 1 of this dissertation has been achieved.

Having developed a model for impact assessment in chapter 7, it was necessary to study the impacts of different construction technologies in a context. For this, there was a need to calculate the actual value of the data on the socio-economic and environmental impacts of different walling and roofing systems. It may be noted that the Objective 2 of this dissertation was to develop a process of calculation and determining the actual values of the socio economic and environmental impacts of different cost effective construction technologies in the context of Ranga Reddy district.

Chapter 8 and 9 described a detailed process of data collection of new construction of different walling and roofing systems based on Andhra Pradesh project experience. In these two chapters, the actual values of the nine socio-economic and environmental impacts of different walling and roofing systems have been calculated. Chapter 11 carried out a detailed analysis of how to calculate life cycle impacts of these walls and roofs with reference to chapter 6 on the repair and upgrading programme of the schools in Ranga Reddy district. The Table 11.17 and Table 11.18 show the actual values of the life cycle impacts of 11 roofing systems and 6 walling systems.

Objective 3 of this dissertation was to demonstrate the selection process of the combination of walling and roofing technologies for those which have optimum life cycle cost of construction, high employment opportunities, low embodied non-renewable and renewable energy, high embodied waste energy and low emission of CO_2 in a particular context.

The demonstration of the real scale impacts in chapter 10 and 11 is very important since it provided a deep insight into the domain of sustainable social infrastructure development. These two chapters will make the decision makers aware of the scale of new and life cycle impacts of different walling and roofing systems on the socio-economy and environment in a context. This will enable them to make an informed choice on sustainable social infrastructure development.

After understanding the real scale impacts of different construction technologies, the decision makers would like to choose the best combination of walling and roofing systems out of the feasible options, i.e., the objective 3 of this dissertation. The best combination will be the one with optimum unit cost of construction, high employment opportunities, low embodied non-renewable and renewable energy, high embodied waste energy and low emission of CO_2 in a particular context. With the help of Table 12.3 and Table 12.4 in chapter 12, one can narrow down the domain of technology options based on which the sustainable combination could be chosen. For example, while brick intensive walls and roofs are sustainable in Ranga Reddy district, micro concrete tile roofing with interlocking stabilised mud block wall will be sustainable in most of the places where the climate is moderate.

Objective 4 of this dissertation was to demonstrate the effect of varying weights assigned to the socio-economic and environmental parameters on the scoring. Chapter 12 of this dissertation has ranked the different options of walling and roofing technologies against the nine socio-economic and environmental parameters by using the impact assessment tool. Figure 12.1 and Figure 12.2 in chapter 12 show the pattern of variation of the lowest scores under all nine parameters by increasing the weights according to a geometrical progression series. This has been done for simplicity and also owing to the fact that a geometrical series magnifies the weights rapidly to test their effect on the minimum indexes. Figure 12.1 and Figure 12.2 show that the minimum indexes tend to be parallel to the X-axis from the weight of 128 onwards, which indicate that the weights are sensitive only between 1 and 128. This is an important outcome of the exercise carried out in chapter 12.

Chapter 12 has demonstrated how the best combination of wall and roof will vary if the highest weight of 128 is assigned to a particular parameter and the rest equal to one. If 100 million rupees (£1.25 million) is spent on school construction in Ranga Reddy district, three out of eleven roofs and five out of six walls will be feasible as sustainable solutions (Table 12.4 in chapter 12). Brick corbel arch roof is the best option for high weight on semi skilled, skilled, renewable energy. It is also the best option when all the weights are same. Solid brick work is the best option for high weight on retention, waste and semi skilled masons. Therefore, brick corbel arch roof with solid brick or rat trap boned wall may be recommended in Ranga Reddy district. From this discussion it may be said that objective 4 of this dissertation has been fulfilled. However, the most desirable solution can be obtained if the nine weights are generated in a real situation by involving the beneficiaries, subject specialists, decision makers, national and international statutes, regulations, etc.

Objective 5 of this dissertation was to enable decision makers to develop databases on new construction and life cycle impacts in other contexts and to select appropriate technologies. Chapter 8 shows the process of calculating the nine socio-economic and environmental parameters in the context of Ranga Reddy district. Chapter 9 demonstrates the process of calculating the nine socio-economic and environmental impacts of different walling and roofing systems as finished products. These two chapters will enable a decision maker in other contexts to develop an area-specific database which is one of the most important components of sustainable construction technologies. As mentioned before, chapter 10 shows the impacts of new construction of 1,068 classrooms adopting 66 combinations of walling and roofing systems. Chapter 11 shows the process of analysing the life cycle impacts of the 11 roofing and 6 walling systems based on the experience of Repair and Upgrading Programme of Andhra Pradesh. Therefore, chapter 8, 9 and 11 will enable a decision maker to develop data on the socio-economic and environmental aspects of construction technologies in other contexts.

After calculating the actual values of the nine socio-economic impacts of the feasible technologies in a context one will be able to calculate the least number of one classroom units, i.e., the most expensive combinations of wall and roof within an allocated budget. This could be done by following the process described in chapter 10. A decision maker will be able to study the impacts of life cycle and new construction following the examples in chapter 10 and 11. Finally, following the process shown in chapter 12 (Table 12.3 and Table 12.4) they will be able to narrow down the domain of technology options based on which the sustainable combination could be chosen. It may be noted that a sustainable option could be chosen if the nine weights are generated in a real situation.

The entire process of impact assessment of life cycle, new construction and scoring has been developed in Microsoft Excel as shown in chapter 1. A decision maker in another context will be able to develop databases on new construction, study the new and life cycle impacts and select appropriate technologies by changing the values of basic building materials, discount rate, inflation, etc., in "A", "B" and "G" in Figure 1.8 (chapter-1).

The above discussion reveals that this dissertation has developed an impact assessment tool (chapter 7) based on the experience of Andhra Pradesh Primary Education Project (chapter 5 and 6). To demonstrate how to calculate the impacts with the help of the assessment tool, data has been developed in chapter 9 and 11. The impacts of life cycle and new construction have been demonstrated in Chapter 10 and 11 by assuming that 100 million rupees (£1.25 million) will be invested for school construction in a district. Chapter 12 shows the method of identifying the sustainable option of wall and roof in the context of Ranga Reddy district. Therefore, it may be said that the aims and objectives of this dissertation have been achieved.

13.2. REVIEWING THE ASSUMPTIONS

The impact assessment and scoring of 66 combinations of walling and roofing systems have been carried out on the basis of 1,068 classrooms, each having 5.5m x 5.5m floor area. It has been assumed that these classrooms will be built on flat land. Therefore, on a comparative basis, eliminating the same type of foundation, floor finish, door and window from the scope of the impact assessment appears reasonable. However, if there are a number of feasible options for foundation, floor finish and door and window, then they should be included in the impact assessment.

The assumption that all the data is based on Jaggamguda, a village in Ranga Reddy district of Andhra Pradesh has enabled the comparative analysis of the impacts of the 66 combinations of walling and roofing systems. By assuming 100 million rupees (£1.25 million) of investment on school construction, as in the District Primary Education Project, has given an opportunity to study the impacts in real scale. Also adopting 1,068 classrooms for impact assessment of new construction and life cycle has provided an opportunity to study the impacts on a comparative basis.

The assumption that a simple method of impact assessment will be acceptable to the decision makers has been tested in South Africa. The assessment tool developed in this dissertation has been adopted in the Eastern Cape Sustainable School Building Programme in South Africa, which is a DFID funded project entitled "IMBEWU II". The model and its results were discussed with the Ministry of Education. After reviewing the results of the impact assessment tool, the Ministry had approved the construction of a demonstration building at Bantwanana, Umtata district, which was acceptable to the community as well. Following that exercise a school building was constructed using cement stabilised mud block that was low cost, labour intensive, with low embodied energy and low CO_2 intensive.

13.3. REVIEWING THE LIMITATIONS

This dissertation is based on the cost of materials in 1995-96 (SSR, 1996) that was approved by the Government of Andhra Pradesh. The repair expenditures of 2000 were recalculated by adopting 1995-96 rates to study the life cycle impacts of the different combinations of walling and roofing systems. Considering 1995-96 as the base year, the life cycle impacts were calculated for a building life of 50 years, recommended by the Bureau of Indian Standard (IS 875, Part 3, 1987). The discount rate and inflation rates of 1995-96 were applied for consistency. While this is old data, one can modify the Microsoft Excel worksheets; "A", "B" and "G" in Figure 1.8 of chapter 1 to update costs, energy, emission, discount rate and inflation in any context and at any point of time. These changes could be done in the charts shown in the screen dump in Figure 1.9 of chapter 1.

While calculating the embodied energy and emission of CO_2 it was found that some of the data such as paints, bitumen and waterproofing compound were not available in Indian context. As mentioned earlier, these have been adopted from the embodied energy of materials in New Zealand (Alcorn, 1998). Chapter 8 has carried out a detailed analysis of the various issues of calculating embodied energy and emission of CO_2, which is adequate for one to develop a complete database in Indian and other contexts. This issue has been discussed in the section on future research.

This dissertation does not suggest final weightings of the nine parameters adopted in the impact assessment; it demonstrates the effect of varying the weights on a geometrical series.

Chapter 12 shows that the weights are sensitive between "1" and "128", which is an important finding. However, there is a need for future research on weighting, which has been discussed in the section on future research.

This dissertation assumes that the walling and roofing options that generate the highest employment obtains the highest score. This has been done to respond to the recommendation of the Tenth Five Year Plan (2002-2007), which emphasises on the employment generation in view of the poverty in India. While this assumption should be revisited with respect to the subsequent Five Year Plans, it appears highly unlikely that the situation will change before 2015, which is the target of the Millennium Development Goals.

13.4. KEY FINDINGS AND CONCLUSIONS: IN THE LIGHT OF IMPACT ASSESSMENT IN RANGA REDDY.

The technologies suggested by the impact assessment tool in the context of Ranga Reddy district will now be reviewed. While rice husk based brick production needs to be encouraged, its CO_2 emission will continue to be a matter of concern. If in a place, use of brick is inevitable, rat trap bonded brick masonry may be recommended since it uses lesser number of bricks and cement than that of solid brick work. This makes the rat trap bonded wall less non-renewable energy and less CO_2 intensive compared to that of the solid brick wall, however, the former is more labour-intensive than the latter. Brick-intensive systems such as corbelled arch roof appear to be a good option. If brick continues to be used as a building material, alternative production technologies such as vertical shaft brick kilns may be encouraged by making provision for incentives.

The general trend of impacts in the context of Andhra Pradesh Primary Education Project indicates that the cement stabilised mud block walling is energy efficient and emission friendly apart from the fact that it acts as an income multiplier. However, there is no technology that could be prescribed as a general solution as evident from the Table 12.3 in chapter 12. Every place has its own set of sustainable technologies for wall and roof and impact assessment will help in deciding that. However, the combination of micro concrete tile roof with interlocking cement stabilised mud block will be an economic solution in most of the contexts because of their low consumption of the basic materials. In a moderate climate, where economy is the most important criterion, this combination many be recommended and also the small scale production of the tiles and blocks may be encouraged to develop entrepreneurs in the rural areas.

One of the important observations is that the solid brick masonry scored high in Ranga Reddy because rice husk was used as fuel. The Figure 10.10 in chapter 10 shows that solid brick wall could have been the worst option in terms of embodied non-renewable energy if coal were used as a fuel for brick production. This indicates that there is a need to examine every situation, as local circumstances may alter expected choices.

It has been stated in chapter 1 that calculation of a final set of weighting is beyond the scope of this research and the varying effects of the weights will be studied in this dissertation. High weights were assigned to the nine parameters one at a time. In each case, rest of the weights were assumed as "1". Chapter 12 has shown that some important conclusions could be drawn from this study. For example, when all the weights are assumed to be same, corbelled arch and rat trap wall, i.e., brick intensive systems turn out to be the best combination in Ranga Reddy. Under the various patterns of weights assigned to the nine parameters (Table 12.3, chapter 12), a particular walling and roofing combination has appeared only twice as best option. This tends to suggest that the outputs of the model are very much dependent upon the weights and the results are difficult to predict intuitively. Figure 12.1 and Figure 12.2 in chapter 12 suggest that none of the weights beyond 128 have any significant effect on the scores obtained by different technologies. It is a very important finding.

By adopting the weights described above, three out of eleven roofing systems and five out of six walling systems have come out to be the best options under various weightings. From Table 12.4 in chapter 12 one can conclude that the walling and roofing systems based on local materials or having low cement and steel consumption have scored highly in Ranga Reddy. Therefore, solid brick wall, rat trap bonded wall, cement stabilised mud block wall, stone roofing and brick corbel arch roof are suitable in the context of Ranga Reddy. The decision maker will choose the combination of wall and roof depending upon that parameter on which the highest weight has been assigned in a context. For example, if unit cost is the most important objective, the decision maker will choose the combination of micro concrete tile roof and interlocking block wall (Figure 12.4, Chapter-12). Similarly, if employing the unskilled workers is the most important objective, then the decision maker will choose stone roof with coursed rubble stone wall (Figure 12.4, Chapter-12).

It may be noted that micro concrete tile roof is cement and steel-based. However, the consumptions of these two materials per unit area are low since it is a light weight roof and the tiles are very thin (8mm) compared to the other roofing systems (at least 100 mm). Similarly, although interlocking mud wall is cement based (10% stabilisation), the consumption of cement per unit wall area is low owing to its thickness of 150 mm. This varies between 380 mm and 200 mm for other walling systems. Owing to these, micro concrete tile roof and interlocking cement stabilised mud block wall became suitable options in Ranga Reddy. It may be noted that these two technologies will be suitable in other contexts as well owing to their low consumption of cement and steel per unit plan area.

13.5. THIS RESEARCH IN THE CONTEXT OF OTHERS' WORKS IN THE FIELD.

The impact assessment tool will enable a decision maker to select the most appropriate construction technology that is low cost, low maintenance-intensive, high labour-intensive and least damaging to the environment in a particular context in India. The following is a discussion on how this research looks like in the context of others' works in the field.

According to Das (2000a), the research and development in the field of cost effective construction technologies started around late 1960s in India, when the Government and the people realised that the country had a lack of adequate social infrastructure such as primary schools, health-care facilities, housing, etc. As a response to this, the Central Building Research Institute, Structural Engineering Research Centre, National Building Organisation, Building Materials and Technology Promotion Council, Housing and Urban Development Corporation and Non-Governmental Organisations such as Development Alternatives, Centre Of Science and Technology For Rural Development, etc., were founded and got involved in supplying cost effective buildings. As mentioned in chapter 2, under the Andhra Pradesh Primary Education Project the research and applications of the above mentioned institutions have been examined.

The investigation revealed that none of them evaluated alternative construction technologies in a context to choose the most appropriate one. Each has been driven by their respective philosophy-based mission, e.g., Development Alternatives promoted primarily mud-based technologies, Central Building Research Institute promoted rationalised use of cement and steel based construction technologies. Apart from the philosophical reasons it is also a fact that they did not have an assessment tool along with reliable database on different technologies.

At international level, most of the assessment tools such as Green Building Tools are focused on environmental aspects only. However, in India there is a need to include the socio-economic aspects of sustainable social infrastructure development. Some of the researchers such as Bose and Nambier (1995), Tiwari et al (1996), etc., have developed evaluation tools for sustainable social infrastructure development in Indian context. While these research works have significant contributions, they are focused on a few components of sustainability. For example, Bose and Nambier's research addresses only the issue of CO_2 emission. Tiwari et al (1996) have developed models to assess the impacts of various construction technologies. Their model is based on unit cost, livelihood and CO_2 emission. It may be noted that instead of combining the effect of CO_2 emission with the unit cost and labour-intensity, they have studied it (CO_2) separately. They did not consider the effect of embodied energy in the model. Tiwari et al's research is founded on database from books, personal discussions, etc. However, they have not discussed the issue of consistency of the data from the different sources. Such research works have not covered all three pillars of sustainability suggested by Plessis (1999) , Cole (1999), etc.

As a sharp contrast, the present research springs from the grass-roots level database, which has been the centre of this dissertation. The database of the Andhra Pradesh Primary Education Project and the Repair and Upgrading of the same buildings formed the premise of the impact assessment tool developed in this dissertation. Therefore, it has been a bottom up approach. This dissertation has shown the process of developing the construction-related data of Andhra Pradesh Primary Education Project. It has also calculated the actual values of socio-economic and environmental impacts of Level-1, 2 and 3 materials. Based on such data, the impact assessment tool has demonstrated the socio-economic and environmental impacts of different construction technologies. One may follow that process to generate a similar database in other contexts. If the assessment tool is widely used in India, there will be several databases in different socio-economic and environmental contexts. Once the regional databases are generated, the National and State Governments and the international funding agencies can use the assessment tool and understand the overall impacts of adopting different construction technologies in the large scale social infrastructure development programmes.

13.6. CONTRIBUTIONS OF THE DISSERTATION IN INDIAN CONTEXT

There are a few areas where the dissertation has contributed substantially. To begin with, it may be mentioned that the impact assessment tool developed in this dissertation is based on grass-roots level project experience – a completely bottom-up approach, which is rare. The demonstration of the real scale impacts is very important since it provides a deep insight into the domain of sustainable social infrastructure development. The quantitative assessment of different construction technologies demonstrated in this dissertation will put an end to ad-hoc decision making, which is the present practice in India.

This dissertation provides the impacts of a variety of construction technologies. In this regard it is important to reiterate that the data of Andhra Pradesh Primary Education Project is the most precious component in the whole process. As mentioned before, the data is based on buildings constructed and ageing under the uniform conditions. Therefore, the data on new construction and life cycle impacts are valuable and rare. It is a rare chance that an experiment could be carried out by adopting so many construction technologies in a Government institutional structure and it is unlikely that there will be another chance in the near future. The Ranga Reddy construction project is like a laboratory. In future, if data on maintenance is collected periodically from Ranga Reddy, the knowledge on life cycle impacts of the 66 combinations of walling and roofing technologies will be enriched.

Another important aspect of the dissertation is the experience of Andhra Pradesh School construction as a background of the assessment tool. This experience, described in chapter 5 and 6, will act as a reference to individuals, NGOs, Government agency, etc., aspiring to venture into sustainable social infrastructure development in a particular context.

The dissertation shows a detailed analysis of how architectural design, site conditions, construction technologies etc., could influence the socio-economic and environmental impacts at village level. The Appendices VII, IX and X show the break-down of site-level impacts, defect mapping and data relating to Repair and Upgrading, which are rare and valuable.

The dissertation provides a detailed knowledge on wide variety of walling and roofing technologies, some of which are being used for the first time in India. The different cost effective technologies explained in Appendix III and Appendix IV will act as examples to the developing countries. This may help them to carry out similar exercises in their own contexts based on the locally available natural resources.

The dissertation will help the decision makers to know why, to what extent and under which conditions they should give incentives for adopting a particular type of construction technology. The results of the impact assessment in a context should be made available to the community in a format suitable for their easy understanding. This will increase communities' understanding on many aspects of sustainable development, particularly the environmental issues.

One of the important contributions of this dissertation is the process of data collection (explained in chapter 1). For example chapter 8 carries out a detailed analysis of the various issues of embodied energy and emission of CO_2 of different building materials including the methodological frame work. This will help to develop complete socio-economic and environmental data in India.

13.7. CONTRIBUTION OF THE DISSERTATION WITHIN THE WIDER CONTEXT OF THE FIELD OF SUSTAINABLE DEVELOPMENT AND CONSTRUCTION

Let us review the contributions of this dissertation in the wider context of sustainable development and construction. In contrast to the general trend of assessment methods mostly being on environmental sustainability, this dissertation has adopted the suggestion of

Todd and Geissler (1999). They suggested that a regionally adaptable system that assesses the "green-ness" of buildings while taking into account of the social and economic issues begins to address the sustainability of buildings. The impact assessment tool developed in this dissertation addresses all three. This assessment tool developed in the context of Ranga Reddy district has been adopted successfully by the planners of South Africa, which has been discussed in the post script. This shows that the tool is regionally adaptable.

According to Theaker and Cole (2001) sustainability is local – the day-to-day experience of local Government gives a more intimate experience of local conditions. This dissertation has dealt with sustainable social infrastructure development primarily from a local point of view (district level). At the same time, once the local levels impacts are known, its influence on the global scale can be assessed.

According to Fricker (2001) we have a better understanding of what is unsustainable rather than what is sustainable. Dahl (1995) suggested that measuring the negative factors preventing sustainability will enable the countries to report, for instance, the progress they are making in reducing damaging activities, even if they have not yet defined clear goals for sustainability. This dissertation measures the negative factors such as CO_2 emission, embodied energies, etc. of the different combinations of walling and roofing systems. Such measurement will allow each country to define for itself how it imagines its ideal future sustainable society and then to report, for each indicator, whether it is making progress towards its own goal, and at what rate.

Let us now look at the views of the international level institutes and forums on sustainable development. The Department For International Development, Agenda 21, the Millennium Development Goals, etc. suggest assessment of human activities, e.g. construction, that are likely to have a significant adverse impact on the environment. They also emphasize that eradicating poverty is an indispensable requirement for sustainable development.

Out of the eight goals of The Millennium Development Goals (2003) this dissertation has shown how the financial pressure on the infrastructure component of goal 2 (achieve universal primary education) could be reduced by using cost effective construction technologies. This will result in creation of more primary schools than the conventional cement and steel intensive systems can provide. The dissertation has also showed that supplying the infrastructure component of the goal-2 (achieve universal primary education) could be viewed as an opportunity for addressing the goal-1 (eradicate extreme poverty and hunger), by adopting labour intensive systems. The dissertation has also shown the extent of environmental impacts of the materials and methods on the environment. Following the suggestions of Lippiat and Boyles (2001) that the answers lie in the trade-offs, the assessment tool calculated the final score obtained by all the nine socio-economic and environmental parameters. Thus the goal-7 (ensure environmental sustainability) of the Millennium Development Goals has been addressed in this dissertation. Therefore, this dissertation has covered the construction related aspects of sustainable development as suggested by the DFID, AGENDA 21 and the Millennium Development Goals.

At international level the issue of life cycle implications has been given a high importance (Cole and Sterner, 2000). However, a frequently held reason for not evaluating the life cycle implications is the lack of appropriate, relevant and reliable historical cost information and data (Ashworth and Hogg, 2000). According to Cole and Sterner (2000), even if the life cycle cost estimates for a whole building are preliminary and approximate, they can still expose significant cost areas and, therefore, provide an informed basis for subsequent planning. However, Cole and Sterner (2000) also observed that life cycle analysis is a data intensive process and the final outcome is highly dependent on the accessibility, quality and accuracy of input data. The most important contribution of this dissertation is the quality of the life cycle data evolved during the Andhra Pradesh Primary Education Project, which has been explained in detail in chapter 1 and 6. This aspect of this dissertation is a trend setter and will help the people involved in social infrastructure development to generate similar data in other contexts.

According to the UNCHS (1991) report most of the developing countries are endowed with abundant natural resources, which can meet the demand for basic building materials. Yet much of these natural resources currently remain unexploited in most developing countries. This dissertation will help them to examine the possibilities of sustainable construction in their own contexts based on the locally available natural resources.

13.8. RECOMMENDATIONS ON THE IMPLEMENTATION OF THIS MODEL

The inadequate amount of funds from revenue collection and India's huge external debt of US $112.54 billion in 2004 (GOI, 2003), indicate that there is an acute financial shortage for developmental works. Chapter 3 has shown that the financial requirement to supply the primary healthcare, schools and housing is about 6.5 times the investment requirement in the construction sector (Tenth Five Year Plan, 2002-2007:39) at 2001-2002 prices. The universal elementary education in India was designed to be achieved by the end of the District Primary Education Programme. However, that did not happen and hence, another programme named Sarva Shiksha Abhiyan (education for all) has been launched in 2001-2002 to achieve universal elementary education.

Under such circumstances this dissertation will be able to help the decision makers to maximise the supply of social infrastructure components within funding constraints. It will also help in partially attaining the environmental goals. Let us understand this with reference to achieving universal primary education through the implementation of the Sarva Shiksha Abhiyan (education for all). Considering the shortage of funds the Government engineering departments will explore the possibilities of cost reduction so that maximum learning space could be constructed within the allocated budget. Now the impact assessment tool will guide the decision makers to select the most economic technologies. This will enable the Government to understand the time required for supplying all the schools required for the universalisation of elementary education.

Let us assume that this process will be followed in all the Indian states (sub-national) implementing the Sarva Shiksha Abhiyan and they will report to the Government of India in this regard. In each state, if labour-intensive technologies are adopted in construction, it will help in reducing poverty and hence, will support the attempt of the Tenth Five Year Plan (2002-2007) to create 50 million employment opportunities during the plan period. Similarly, construction technologies based on low embodied energy and low CO_2 emission will reduce environmental damage owing to construction. If from each region, such analysis is sent to the Bureau of Sarva Shiksha Aviyan, they will be able to assess the socio-economic impacts on the country as a whole and report it to the international community.

The Indira Awas Yojna has been framed in the light of the National Housing and Habitat Policy (1998) for the poor and the deprived. It envisaged construction of 2 million additional houses annually, of which 1.3 million units were to be in the rural areas. This scheme is for people below poverty line. At present, they have no access to technical support for cost effective construction. Their only source in this regard is the Government engineers at the block level who use only reinforced cement concrete. Based on district level resource mapping report, the impact assessment tool will help in identifying the cost effective and labour-intensive technologies with low embodied energy and low CO_2 emission. In the context of Indira Awas Yojana, the weighting for unit cost, retention and labour intensity may be higher than the environmental parameters. However, the impact assessment of the environmental parameters is important considering the scale of construction. If the cost of environmental damage reversal of a technology with low unit cost and high labour intensity is significant, the decision makers may subsidise the expensive technologies, which are environment-friendly. The district collectors, who happen to be the head of the fund release for Indira Awas Yojana, may carry out the impact assessment by involving their associated engineering departments. The impact assessment results at regional levels will help in the State and National Government for their policy reforms.

The social infrastructure development projects in India are implemented by the different Ministries such as Human Resources Development, Environment and Forest, Non-Conventional Energy, Rural Development, Urban Development, Home Affairs, etc. Discussion with the Ministry of Forest and Environment and the Ministry of Home Affairs revealed that at present, the Ministry dealing with livelihood generation does not know quantitatively whether the increased human activities are affecting the environment, which is the concern of the Ministry of Environment and Forest. If the result of impact assessment by one Ministry is shared with the other Ministries and the development agencies, there will be less chance of making mistakes and clashing with each others' objectives.

One of the most important aspects of the assessment tool would be to generate data on the total amount of CO_2 emitted by the construction sector. If the Government of India can show that alternatives to the steel and cement-intensive construction systems will reduce CO_2 emissions significantly, it can go for carbon trading with a developed country. Thus, India can earn money and hence, incentives may be given to the clean construction material production industries to encourage them.

Some of the most significant actors in promoting sustainable construction technologies are the Municipalities in small and mid-towns and Corporations in cities. These agencies can promote green building systems by providing incentives to the builders and the owners. The tool will enable them to assess the technologies adopted in a particular building plan which has been submitted to the municipality for approval. The assessment result will determine whether the suggested technologies should get rebate on design-approval fees and also house tax.

It has already been mentioned in chapter 7 that the field experience in Orissa and Andhra Pradesh had revealed that there is a lack of awareness regarding environmental protection among the communities. If a rural primary school or healthcare building is constructed in a settlement, the result of the impact assessment should be presented in a suitable format for their easy understanding to explain the environmental implications. This will increase their awareness on environment. After this, they may be told that if they adopt green building techniques, additional facilities such as boundary wall, extra floor areas, etc., will be provided to them as incentives. This may result in a favourable situation for the decision makers at community level to promote green buildings and technologies in public and private building construction.

In the recent past there has been a series of disasters in India causing unprecedented destruction and loss of human lives and properties. The Government of India has been rebuilding the damaged social infrastructure in Orissa (super cyclone, 1999), Gujarat (earthquake, 2001), etc. The latest blow on the national economy of India is the damage owing to the tsunami (December, 2004) in Andaman and Nicobar Islands and parts of the east coast of India. It is important to note that the reconstruction programmes have all been implemented without any quantitative socio-economic and environmental assessment of different construction technologies. According to the revenue department of the Government of Orissa (December, 1999), more than two million houses had been damaged in its 12 districts. Out of these, about 0.84 million houses were completely destroyed and the remaining 1.2 million houses were partially damaged. Financial support from all over the world has rebuilt the damaged infrastructure in Orissa without any quantitative assessment of the socio-economic and environmental impacts of the new construction, let alone life cycle.

Usually the Ministries concerned with post disaster interventions say that they have no time for any kind of research. The impact assessment tool will take the least amount of time to assess the impacts of the rehabilitation and reconstruction whenever a disaster strikes.

Cole (1999) is among other authors who provided a complete picture of life cycle analysis of construction by defining the scope and boundaries of environmental assessment method. Figure 2.1 in chapter 2 shows a conceptual framework that can be used to illustrate the scope and boundaries of environmental issues in current building assessment methods. It consists of three primary dimensions, viz. Criteria, Time and Scale. Each axis consists of a firm line and a broken line indicating the predictable and unpredictable part of life cycle assessment. If the Andhra Pradesh schools are monitored periodically, information on the socio-economic, environmental impacts of the school maintenance along with their influences on the communities will enable us to understand Cole's diagram in a real situation. It may perhaps help in transforming parts of the broken lines (indicating uncertainty) of Figure 2.1 into a firm line (predictable).

13.9. OPPORTUNITIES FOR FUTURE RESEARCH.

There is an urgent need for generating databases on embodied energy and emission of CO_2 of the different construction materials to facilitate a single source of information. This needs funding and time and also a motivated group of researchers. Chapter 3 and chapter 8 have shown that in India there are different sources of information providing different figures on the same issue. The most important aspect of generating a single data-source of energy will be to identify the best source. The single source as a handbook should show the type and quantity of non-renewable, renewable and industrial and/or agriculture waste energy and recycling in the different regional and local contexts. The regional variations could be significant, e.g., while electricity in many states is coal based, there is hydro electricity and nuclear energy based power generation in different parts of India. Therefore, the embodied production energy of various building materials will vary from region to region. The energy handbook has to clearly define the system boundaries. Apart from that, the data source reliability, international differences and thermal energy content of feedstock materials, etc should be discussed in detail.

The schools constructed under Andhra Pradesh Primary Education Project are growing old and are going to offer reliable data on life cycle implications. The buildings should be monitored in a similar way as was done by Department For International Development in 1998 and the following interventions in 2000. There is a need for exploring the existing methods such as Building Research Establishment Environmental Assessment Method before the next intervention to enrich/improve the data acquisition process. The revised database after every five years may be published, which will provide increasingly reliable information on the life cycle impacts. This will make the impact assessment tool robust.

The entire dissertation is focused on the walls and roofs only. The next step would be to prepare a database on the different options for foundation and finishing items so that one could study their implications. For example, the finite source of Tandur stone may face dire consequences, if we start depleting them recklessly by consuming them in all the floors in Andhra Pradesh and its adjoining states just because they are inexpensive at present. There is a wide variation of finishes across the country. A database for analysis of rates will upgrade the impact assessment process and it will be able to assess a complete building.

Research on the weightings is very important. The scoring in chapter 12 will be meaningful, if the correct combination of the nine parameter-weights and two group-weights could be calculated. An in-depth research is necessary to explore the sensitivities of the weights. However, the use of the assessment tool based on a consensus decision and the post implementation evaluation will throw light on this issue. Therefore, the theoretical research along with the field evaluation results may converge to a reliable source and guideline for determining the weights in different contexts. Further research has to study the implications of the group weightings, which has been assumed to be "1" in this dissertation for simplicity.

The process adopted in the context of Brownfield Regeneration (Kogelheide, 2004) demonstrates the actor collaboration to prioritise objectives in the development of a "Sustainability Assessment Tool". This process appears to be a good model of beneficiary participated weighting method and can influence project development from early stage by facilitating face-to-face communication between local authorities, planners and citizens. However, as mentioned in chapter 2, Steen (2001) refers to Fallenius et al (1997) and states that investigations show that ordinary consumers have a very limited ability of understanding complex environmental information. Steen's opinion appears to be valid in Indian rural context in the light of the field experience in Andhra Pradesh and Orissa. However, the community awareness has increased significantly in the states that had implemented the District Primary Education Programme (Das et al, 2004). The ongoing programmes such as Sarva Shiksha Abhiyan (education for all) also followed the District Primary Education Programme's principle of community-centred development. Therefore, there is scope for conducting a weight-assigning workshop in these programmes by involving the communities following the Brownfield Regeneration process. Similarly, the Analytical Hierarchical Process developed by Thomas Saaty (Nataraj, 2005) should also be examined for determining the weights.

In view of the above discussion, it may be said that the dissertation may enable the Government of India to adopt the suggestion of the United Nations Conference on Environment and Development (1992 updated: 1999). According to that, the Environmental Impact Assessment should be adopted as a national instrument. Once that is done, it will be easy for India to achieve the Millennium Development Goals' emphasis that the principles of sustainable development should be integrated into country policies and programmes. However, this dissertation went beyond the issues of environment and has considered the socio-economic aspects as well and hence, is based on all three pillars of sustainable development. This will enable the decision makers to supply sustainable social infrastructure in India.

13.10. POST SCRIPT

It has been mentioned before that the model developed in this dissertation has been tested in the Eastern Cape Sustainable School Building Programme in South Africa. It is a DFID funded project entitled "IMBEWU II". By adopting the model, impact assessment was carried out in a village named Bantwanana, district Umtata, Eastern Cape. The impact assessment revealed that cement stabilised mud block based construction technologies were sustainable since they were of low unit cost, labour intensive, with low embodied energy and low CO_2 emission intensive. This was approved by the specialists of the Department of Education after considering the condition of the national economy, poverty at village level and fragile environment of the province. These issues were also discussed with the community where the school was proposed to be constructed. The community accepted the suggested technology since they realised that the project will lead to increased income generation than the conventional construction systems. Following that, a complete school building has been constructed with cement stabilised mud block. The school drop outs of the village were trained for block production. This was an alternative to the brick built schools where the bricks were brought from long distances, in which, a major portion of investment on construction went out of the villages. Following the success of this project, the Ministry of Education, Eastern Cape has decided to replicate this project by spending 50 million Rands (£5 million) in the 2006-2007. (e-mail: John Shotton, DFID consultant, June 2005). The complete school campus with classrooms and play facilities was inaugurated in June 2005. This shows that the developed assessment tool is replicable and has been used outside India.

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